FUTURE SPORTSCAR: HOW PORSCHE WON LE MANS WITH A 2.0L ENGINE

AUSTRALIAN

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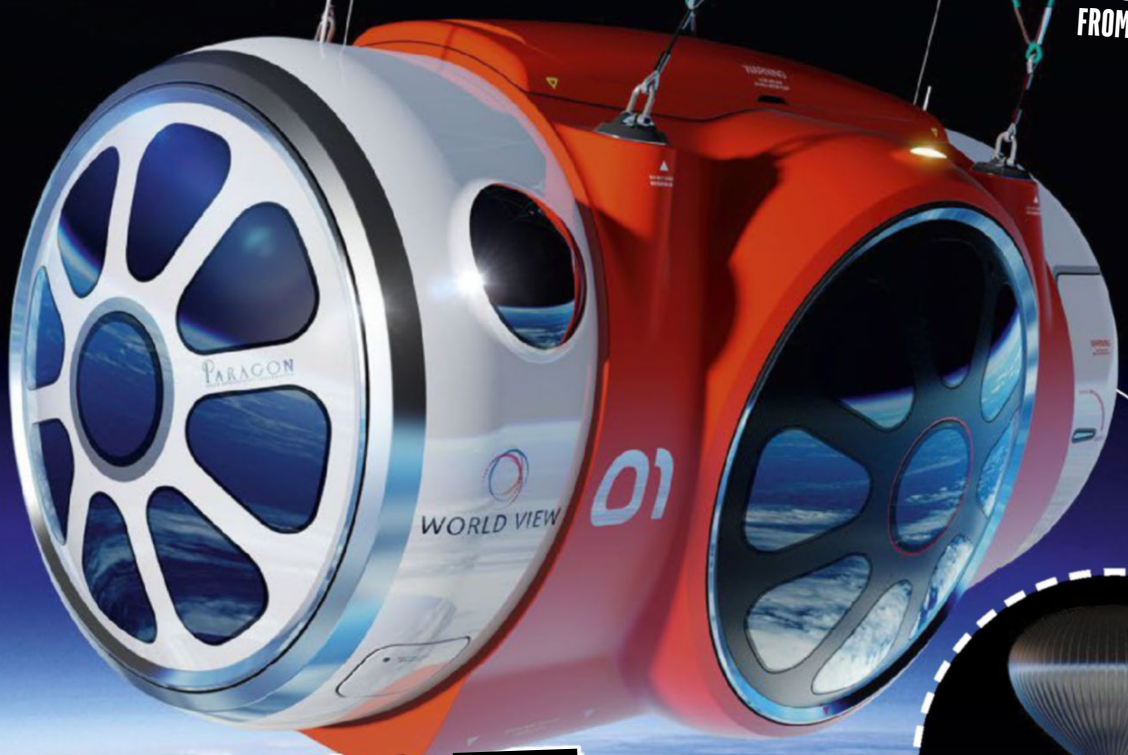
SCI-FI SPECIAL
VERY SHORT FICTION FROM THE WORLD'S BEST



SPACE TOURIST

Scared of rockets? There's a gentler, more civilised way to (almost) get to space

SURVIVING A SUPER-DROUGHT
What happens when it stops raining, forever?

SO CLEAN, SO SICK
Antibacterial tech is killing your microbiome - and you

PLUS! Google's weirdest projects · A 3D printer that doesn't stink → Bone-conducting headphones · Fireproof data storage + MORE!

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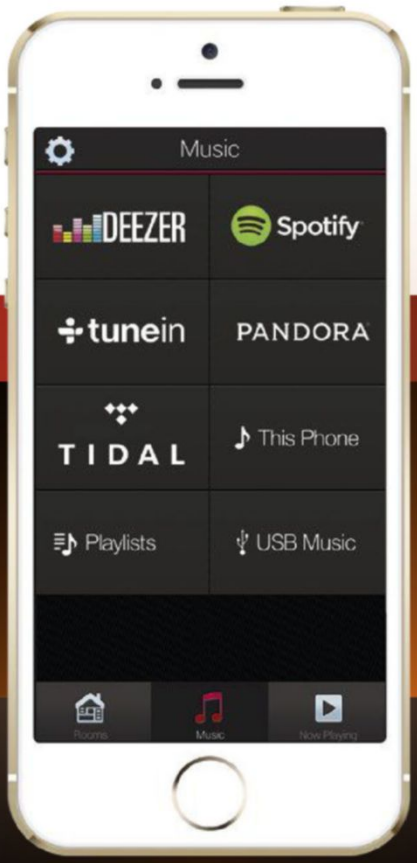
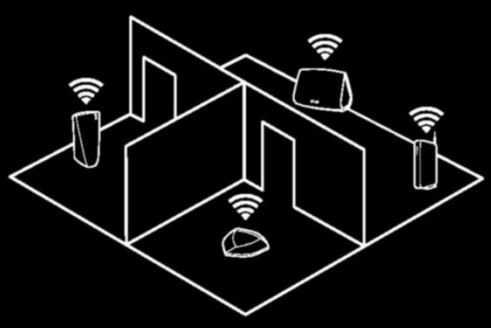


www.**heos**.com.au

MULTI-ROOM

EVERY ROOM DESERVES ITS OWN HEOS.



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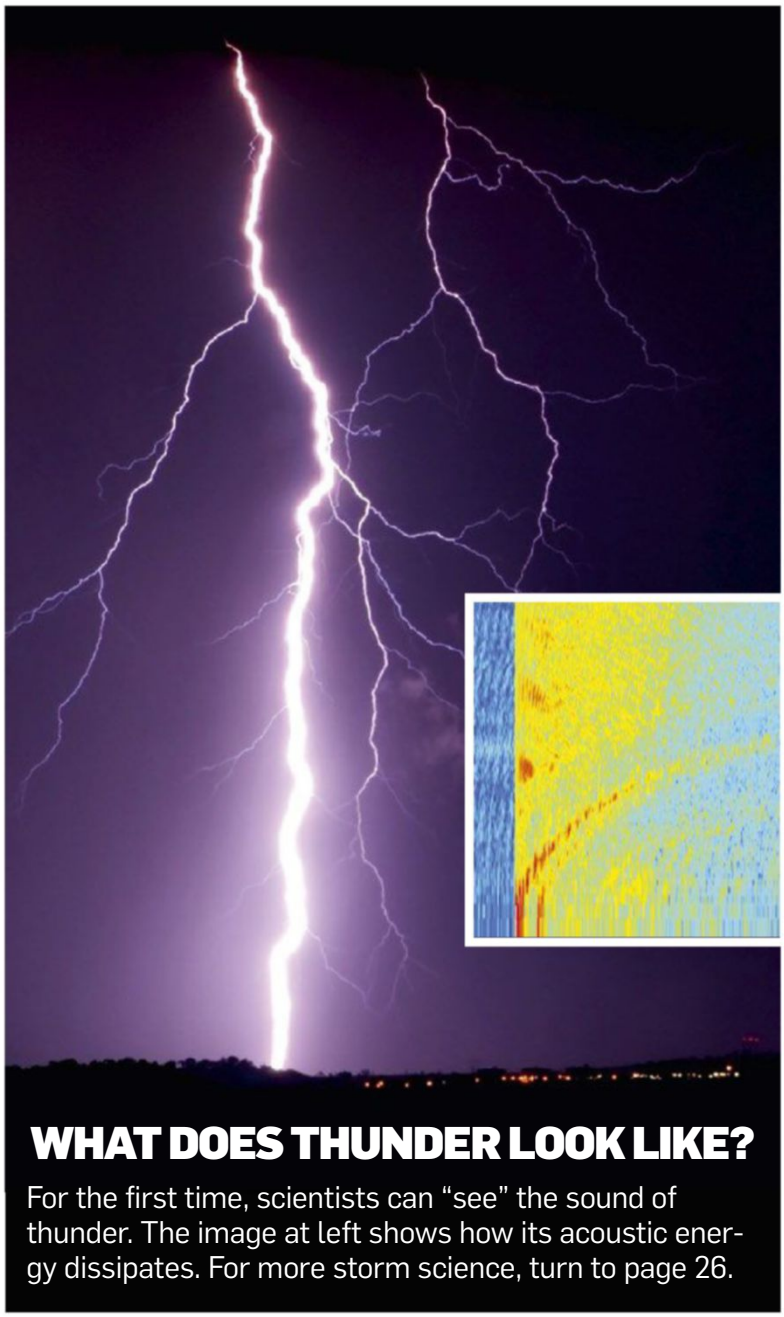

WHAT DOES THUNDER LOOK LIKE?

For the first time, scientists can "see" the sound of thunder. The image at left shows how its acoustic energy dissipates. For more storm science, turn to page 26.

FROM THE ARCHIVES: A Brief History of Extinguishing Fire

In Manual this month, we feature a project that uses sound to put out fire (page 73). We've written about creative ways to snuff flames before:

DECEMBER 1937
An inventor in New York thought one water hose wasn't enough. He devised an octopus-like sprinkler system with eight hoses. It was mounted on a tractor that he could drive through orchards and farms when fires broke out.

OCTOBER 1938
Find yourself without water? Perhaps there's some dirt around. We described a unique tool that used rotary blades to scoop up sediment and spray it over blazes.

JUNE 1942
During World War II, we covered many new technologies designed to help the military. One used carbon dioxide to extinguish fires that broke out on plane wings during combat. It was a different age...

Earlier this year we spent a week swabbing surfaces around the office, including yoga balls, kitchen floors, and bathroom benches. We were afraid to see the results—and for good reason. They're on page 55.

30

Percentage of all diamonds that are sold to consumers (the rest are sold to industry)

To brush up on the latest diamond science, turn to page 30.

US Volume 287 No. 2

The best stories are the ones we tell tomorrow...

08 / CONTENTS / 15

DISPATCHES FROM UNUSUAL FUTURES

Ten of the brightest minds in science fiction imagine how we will live—on Earth and beyond—in the decades and centuries to come.

PAGE 56

Featuring

Departments

ON THE COVER

A World View Experience balloon gondola (balloon inset). Illustration by PriestmanGoode

ILLUSTRATION BY JIM BURN

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Editor's Letter

Alcohol: The Human Obsession

The feature about space tourism via strato-balloon you'll read on page 36 this issue is equal parts fascinating and exciting. But for me, one small paragraph stands out. The company building this unique travel experience has already said the capsule that hangs from the balloon and gives travellers a mind-enhancing view of their planet below... will serve drinks.

And of course, every adult human knows that when we say drink, we mean Drink. Ah that devil drink, scourge of civilisation since... well, archaeologists tell us the fermentation of proto-wheat grains into beer was what kickstarted agriculture. And it makes sense. Why exchange hot, nutritious meat for horrible corn meal flatbreads and insect-infested wheat mash? Unless, of course, you can use the stuff to get off your face.

I don't mind a drink. I like my fermented sugars with ice, and perhaps a slice of something with high citric acid content. But the idea that a bunch of actual, qualified astronauts will, perhaps just five years from now, unstrap their five-point-harnesses and start serving gin and tonics on the edge of space is somehow... depressing.

Alcohol - or more properly, ethanol - is a strange drug. Chemically, it's extraordinarily simple. Just six hydrogen atoms, two carbons and an oxygen. Compare that to "(RS)-1-(Benzo[d][1,3]dioxol-5-yl)-N-methylpropan-2-amine", which is what IUPAC calls MDMA - better known as Ecstasy.

Apart from alcohol's nearly universal acceptance across almost all cultures, it's one of the few psychoactive chemicals that can be taken in small but effective doses, for a lifetime. The vast majority of users do not develop a dependence. And yet make no mistake, alcohol is not just psychoactive, it's also neurotoxic. It's a proper dangerous drug. It can and does destroy lives. It all depends on your personal neurology.

Humans can take this drug simply to enjoy whatever beverage the alcohol is mixed into. As a (very) general rule, only the young or alcoholic "use" the stuff as a drug. Why do I mention this? Because no one takes ice or shoots up heroine in a casual, barbie-at-the-beach kind of way.

But alcohol isn't unique. There's another drug that could function in exactly the same way, if only we'd let it. Cannabis - or whichever of its other roughly nine thousand names you'd prefer to know it by - can also be taken as a mild, "aren't these cookies fun" hit. You can smoke a joint or punch a cone (I love that terminology, it's hilarious) with the same kind of casual abandon as you share a cold one or a glass of bubbly.

And yet, one drug is fine, the other contraband. Why does alcohol have this special status that other drugs don't? Hell, when the US tried to ban alcohol, it nearly tore the country apart. I have no idea how the various Muslim nations manage it. Why do most of us think ethanol is fine, while a significant enough number of lawmakers can maintain the position that THC is bad?

Australia, as we're told, is a nation of drinkers. Sometimes that's a source of pride, other times a source of deep concern. But here's a near-universal truth: if Aussies aren't working, they're drinking.

What's my moral point here? I'm not sure I'm making one. Except to say this: when you spend $13,000 to take a balloon ride 30 km straight up, and you behold your world as a single, fragile bubble hanging in a vast sea of nothingness... will the experience be better, half cut?

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POPULAR SCIENCE

Issue #81, August 2015

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JUNE 2015

CONCERNED YOUTH

Q:

I'm 14 years old, and a longtime reader of *Popular Science*. In the June 2015 article "Long Live the Mammoth," Beth Shapiro neglects a crucial point when talking about the pros and cons of de-extinction. Couldn't bringing back extinct species have negative impacts on other members of the ecosystem, and even lead to the extinction of other species?

Ronnie Eytchison

A:

While it is impossible to predict every consequence of releasing a species into the wild, one critical component in selecting a species for de-extinction is to carefully evaluate risk at each stage of the process. This includes not only technical and ethical risks, but also ecological risks. To my mind, the goal of de-extinction technology is to restore missing components of an ecosystem so as to protect species that are alive today.

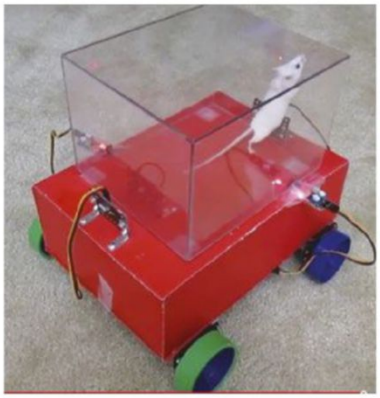
Beth Shapiro, evolutionary molecular biologist at the University of California at Santa Cruz, and author of *How to Clone a Mammoth: The Science of De-extinction*

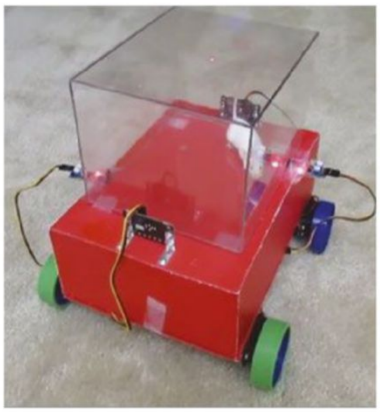
TWEET OUT OF CONTEXT

No safety glasses—tsk, tsk, tsk...
@silentrnajority

WORD FROM THE WISE
As a librarian who has taught people how to do online research for 19 years, I have learned that no algorithm or "smart filter" can regularly provide and top-rank scientifically rigorous results for online medical searches ["Google Flunks Out of Medical School," June 2015]. We must all objectively evaluate the quality and validity of the information we find on Google.
John Hogle

A MORE PERFECT WORLD
I was amazed to read the criticism of stem-cell therapy from bioethicist Leigh Turner ["The Cure-All," June 2015]: "People are paying a lot of money for these treatments without any assurances." When was the last time a doctor guaranteed a treatment and/or gave your money back for a failed treatment? If you can find a doctor like that, please, let me know!
Bill Nicholson





Rodent Control

Reader Brian Byon from Johns Creek, Georgia, invented a robot that he says, "can obey virtually any living organism." In this case, it detects a mouse's movements through one of four sensors, each programmed to move the machine in a different direction.

HAVE A COMMENT?
Write to us at
letters@popsci.com.au

Choose Your Own Adventure

On page 36 we describe two very different journeys to the edge of space. If you were offered a seat, which would you choose: spaceplane or stratospheric balloon? **Tweet your answer to @popsciau #spacetrip**

LEFT TO RIGHT: ILLUSTRATION BY CHRIS BUZELLI; COURTESY BRIAN BYON

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TAKE HILLS WITHOUT BREAKING A SWEAT

Commuters love nothing more than blowing past hipsters on fixies. That's one reason the 45 km/h Stromer ST2 electric bike is a total joy for urban cyclists. With a 145-km range—twice that of other e-bikes—you can forgo work altogether and head for the hills.

The ST2 packs a 48-volt battery in the frame's down tube, evenly distributed for balance—another e-bike first. It also stretches battery life by way of regenerative braking. A gyroscope and accelerometer further boost efficiency by adjusting battery output while the bike is in motion.

Pedalers will love the peripherals too. An onboard touchscreen displays your speed and power mode. Riders can customise the level of motor assistance by programming a custom profile; torque, pedal sensitivity, and power-assist level can all be changed on a whim or saved for later use. The bike also connects to Global System for Mobile Communications (GSM) data networks on its own, without a data plan, so it's always connected. In the event it's stolen, GPS allows you to track it with your smartphone and lock it down remotely. Oh, and it looks like a two-wheel urban assault vehicle worthy of the Dark Knight. Eat your hearts out, Boy Wonders.

DAN KOEPPEL

STROMER ST2
Price $9,399 (est)
Max Range 145 km
Weight 28 kilograms

PHOTOGRAPH BY *Jarren Vink*

ELEVEN WORDS THAT SPARKED A REVOLUTION

"Wait a minute, wait a minute, you ain't heard nothin' yet."

Al Jolson's first spoken words in *The Jazz Singer* mark the first appearance of synchronized dialogue in a feature-length motion picture. Art mirrored life. Moviegoers truly hadn't heard anything like this before. And when they did, they wanted to hear more. *The Jazz Singer* had less than two minutes of spoken dialogue. But it sparked a revolution nonetheless.

The Jazz Singer, 1927

SOUND CHANGES EVERYTHING

Pictures are pictures. Pictures with sound are transformational. That's why *The Jazz Singer* hit Hollywood like a seismic wave. In its wake, silent films have all but disappeared.

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Obsessed

Some things are just...better

LINDSEY KRATOCHWILL

(Prices are shown in US dollars... which means you need to add an extra 30% more or less. The GST isn't looking so bad now, is it?)

1 DEATH STAR LIGHT-UP BEACH BALL
SwimWays lets you flaunt your *Star Wars* fanaticism ahead of this year's big-screen installment. It might not have planet-destroying lasers, but with embedded LEDs, you can use your imagination. **$7**

2 CONNECTED COLLAR
DogTelligent's Connected Collar quiets unruly pups—and trains them to stay that way. An ultrasonic speaker emits a sound that discourages barking, plus the collar works as a virtual fence and leash. **$130**

3 LUNA
Sleep is a big deal. So the Luna smart mattress cover uses sensors to track your sleep, and integrates with smart-home devices to control lights or a thermostat to create the optimal sleep environment. **$235**

4 HARDWARE STORE SAW
Brooklyn Tool & Craft's short-bladed saw has a unique tooth design that can handle both rip and crosscut jobs. The blade's diagonal scales and measuring tools help you convert to metric or check angles without reaching for the toolbox. **$149**

5 WASTED SEA STAR PURPLE PALE ALE
Next time you reach for a cold one, the brewers at Rogue hope you'll think of the disease that's killing millions of starfish. The brewery teamed with the Partnership for Interdisciplinary Studies of Coastal Oceans to create this pale ale. Some proceeds will go toward researching sea star wasting. **$6.75**

6 MAP OF LIFE
For backyard ecologists and curious travelers, Yale University's app makes learning about nature simple. Using your location, it helps you identify, say, what species of frog or tree you've found, and can alert you to others likely nearby. **Free**

7 BRAUN SERIES 9 SHAVER
Braun's most efficient shaver yet isn't just great at eliminating tough hairs that grow in strange directions. Its pivoting head and individually floating cutting elements can make a three-day beard disappear with fewer strokes. **$350**

8 SURVIVAL LACES
Get yourself out of any bind with these shoestrings. Inside the extra-strong paracord laces you'll find fishing line, tinder, and a flint rod that can help start a fire. **$15**

9 *THE MAN WHO WASN'T THERE*
Science journalist Anil Ananthaswamy's new book explores quirks of the mind with stories about people who lose their sense of self and believe they aren't alive. **$27**

10 *BIG BLUE LIVE*
Dive deep into the ecosystem of the Monterey Bay National Marine Sanctuary with the BBC and PBS. Over the course of two weeks, they'll air—on TV, streaming online, and through social media—a live show that takes viewers to the wilds of the West Coast to see humpback whales, sea otters, great white sharks, and other creatures up close. **Aug. 31**

FROM TOP LEFT: COURTESY DOGTELLIGENT; COURTESY SWIMWAYS; COURTESY ROGUE; COURTESY PENGUIN RANDOM HOUSE; COURTESY TYSON V. RININGER /PBS; COURTESY BRAUN; COURTESY WASATCH OUTDOORS; COURTESY LUNA; COURTESY YALE UNIVERSITY; COURTESY BROOKLYN TOOL & CRAFT

CADILLAC INTRODUCES LIGHTWEIGHT LUXURY

Weight is a problem when it comes to fuel economy. The heavier something is, the more energy you burn moving it down the road. The engineers at Cadillac tackled this problem head-on with the new CT6. Rather than relying on expensive carbon fibre or heavy steel, they created a lightweight chassis from a new composite. The result combines 11 materials including high-strength steel and lightweight aluminum, shaving 90 kilos off the traditional chassis.

Available as a hybrid—making it Caddy's first full-size electric luxury sedan—the car's drivetrain takes fuel efficiency a step further. An 18.4 kilowatt-hour lithium-ion battery powers an electric variable transmission capable of boosting acceleration without spasmodic jolts. As for the petrol-powered half, it's a small 2.0-litre four-cylinder engine. Combined, they provide the CT6 with a respectable 249 kW.

All this adds up to a luxury hybrid with less than half the thirst of its petrol-powered counterpart. But true Caddy lovers will appreciate the new agility brought by the car's electric engine. The CT6's rivals might want to invest in a treadmill.

JOSEPH OROVIC

DESIGN OF THE MONTH

2016 Dodge Viper ACR

The 2016 Dodge Viper American Club Racer unabashedly exploits every downforce-enhancing body attachment imaginable. It sports a massive carbon-fibre rear wing, a detachable extension for the front splitter, sinister-looking dive planes, and a hood with removable louvres. Topping out at 285 km/h, it's the fastest street-legal track Viper ever.

FROM TOP: COURTESY GM; COURTESY DODGE

HOW YOUR JAWBONE CAN IMPROVE YOUR TUNES

Unless we're swimming, or have our heads down on something, every sound we hear, apart from our own voice, propagates through a gas (the air), and is picked up by our eardrums and turned into nerve signals by the cochlear.

But while sound transmits through air pretty well, it actually does so even better through a solid. The speed of sound through air is around 343 m/s, while in steel it's 6100 m/s. It's not quite as fast through flesh and bone, but the superior sound-*carrying* properties of solids can be exploited to create a very unique pair of headphones.

Using a pair of transducers in close contact with the wearer's skull, vibrations travel through the bone and are picked up by the inner ear – bypassing that pesky, rupture-prone eardrum. Aside from headphones, bone conduction technology is used in a few niche products, such as Google Glass, hearing aids and even special communication systems for scuba divers. Here are a couple you can buy today. **LINDSAY HANDMER**

DAMSON HEADBONES

Originally launched via Kickstarter, these Bluetooth headphones are now out for general distribution. The Headbones sit behind the head, with over-ear supports and transducers that squeeze tight in front of the ears. They also include a pair of plug in earbuds. The sound is hard to describe - it's almost as if it's coming from inside your own head, yet it's still possible to hear other noises perfectly. Sound quality is... okay - bone conduction doesn't have the same frequency response as normal headphones, so music can lack definition and clarity, and bass suffers. Still, the main aim for the Headbones is for use when exercising, so pure sound quality isn't critical. Importantly, they allow the wearer to still monitor their surrounds while running or riding. There is a fair bit of external noise from the transducers when at full volume, so they're not exactly sociable when used on the bus or train. Still, for folks who want a pair of futuristic exercise headphones, the Audiobone is a solid choice.

Price: $199
Score: ★★★★☆
www.damsonaudio.com

WANT MORE CHOICE? AfterShokz has bone conduction headphones, available in both a wired and wireless model. The Bluez 2 uses Bluetooth and gives six hours of playback for $129. The cheaper Sportz M3 wired headphones have a built in-line amplifier that runs for 12 hours and cost $80. Sound quality is on par for bone conduction.
www.aftershokz.com

BONE OF CONTENTION

Bone conduction allows a physical design that doesn't block the ears, and doesn't rely on having little bungs jammed down in there, so it's great for exercise. But bone works best at "supplementing" audio, not taking care of the whole spectrum. We'd like to see a hybrid system that uses bone for mid-range, and still has buds for bass and treble. That could offer truly intense, in-your-head sound.


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The Setup

HARDCORE BUSH GEAR TO SAVE YOUR LIFE—AND THE WORLD

Cooking steaks, purifying water, and lighting a campsite all require cleverly designed gear. But that doesn't have to be exclusive to those regions beyond the black stump. Similar conditions exist all over the developing world. Now the gear that outdoor companies have spent years developing for adventurers and survivalists are playing important roles in low-resource areas.

HEATHER HANSMAN

1

MSR SE200 COMMUNITY CHLORINE MAKER

For 25 years MSR has made lightweight, portable water filters for backpackers and soldiers. It has now employed that expertise to create the SE200. It's a chlorinator that uses table salt, water, and a 12-volt car battery to make enough chlorine to kill waterborne pathogens, turning a 55-gallon drum of tainted water drinkable. Health workers will use it to supply remote villages with clean water. **$320**

2

GOSUN SPORT

GoSun's portable solar stove was designed for car camping and barbeques. Parabolic reflectors surround and heat a borosilicate glass tube—which holds your food of choice—up to 290 degrees Celsius. In full sun, it can cook up a snag in less than 10 minutes. Last year the company brought a less-expensive model of the stove to Guatemala, where it reduced cooking costs significantly. **$335**

3

GRAVITYLIGHT

Kerosene lanterns are standard in developing countries. But they're expensive and emit deadly fumes. The World Bank estimates that for the 780 million women and children who breathe them in, it's like smoking 40 cigarettes a day. To clear the air, GravityLight's upcoming GL02 powers lanterns with kinetic energy. A 12-kilogram weight hanging from the lantern drops 180 cm on a high-torque drive sprocket, which connects to a DC generator. A three-second drop powers an LED for 20 minutes. The company has tested it in more than 1,300 off-grid households. **Price not set**

PHOTOGRAPH BY *Jarren Vink*


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Standout

IT'S A BATTERY!

You Can Finally Afford a Tesla

Installing solar power at home is good for your wallet and the environment, but storing it is no easy feat. Until recently, the process involved connecting a series of finicky, fragile, glorified car batteries. The Powerwall, unveiled by Tesla Motors CEO Elon Musk earlier this year, is no DIY project. It's a simple plug-and-play home lithium-ion battery aimed at changing the way people think about and store energy.

The Powerwall's large curvy case is the size of a futuristic body board, and it's meant to be mounted on a wall - like art. It draws electricity from the grid when demand and rates are low, or sucks it from solar panels atop your roof (panels sold separately, natch). The energy is saved for use during peak power-demand hours, when the power companies raise rates, or as backup during a blackout.

It fits in nicely with another Musk-backed company: SolarCity. But its creators say that Tesla Motors' prior research into electric cars is what made it possible.

The Powerwall comes in two models with different storage capacities and purposes. Aussie prices are yet to be set, but the 7-kilowatt-hour model wholesales for US$3,000 ($4030) and is designed specifically for daily solar-energy collection and discharging. The 10-kilowatt-hour model could cost US$3,500 ($4700) and is meant to store energy for weeks at time as backup. Up to nine Powerwalls of each type can be connected for even greater capacity.

Here in Australia, the number of solar installations is growing. And with the price of solar energy systems steadily declining (6 to 8 percent a year since 1998), analysts expect solar energy to reach price parity with the larger, fossil-fuel-dominated electrical grid as early as 2016.

Solar junkies aren't waiting. Musk recently said the Powerwall was sold out in the US until mid-2016, though customers can still place orders online. Based on potential future savings, it might be well worth the wait.

CARL FRANZEN

TESLA POWERWALL

Dimensions
1300 x 860 x 180mm

Weight 100 kg

Colors Prototypes include white, charcoal, red, and blue

Models
•10 kWh $4,700
For backup
•7 kWh $4,030
For daily cycle
(wholesale price)

PHOTOGRAPH BY ***Jarren Vink***

5.7

Number, in millions, of virtual-reality devices projected to be sold in 2015

The Camera That Makes Virtual Reality Feel Real

Facebook, Google, HTC, and plenty of startups are betting big on virtual reality. But VR headsets could join the graveyard of overhyped gadgets if there's nothing to watch. Luckily production houses and filmmakers are working on realistic virtual experiences. Though it's going to take more than a camera that can shoot 360 degrees of footage.

Arthur van Hoff, co-founder of virtual-reality studio Jaunt VR, is a tinkerer. At age 12 he made a working photocopier out of LEGO and a felt-tip pen, and he used that ingenuity to build the Jaunt prototype camera. It's made of 16 modified GoPro cameras housed in a 3D-printed carousel. Jaunt's fleet of 20 has logged hundreds of hours of footage, like Paul McCartney performing "Live and Let Die" and Yahoo Screen's sci-fi comedy *Other Space*. But the real innovation comes after the shoot.

As is, the picture looks flat (Jaunt calls it "2-and-a-half-D"). For normal 3D movies, a pair of stereoscopic cameras shoot two versions of each scene. They're split into separate feeds—one for the left eye, one for the right—and projected on top of one another, while polarised glasses trick the brain into seeing depth.

Things get messy when 16 cameras are shooting in 16 directions. So Jaunt created a virtual camera. Software synchronises all the video streams to make it appear as if they were shot by a single camera at the center of the array, and turns the footage into two feeds for the left eye and right eye. Now when the evil villain lunges at you, it feels so realistic, you might forget you can take off the headset. **ANDREW ROSENBLUM**

COURTESY JAUNT VR

Form Factor

BACKUP THAT LOVES PUNISHMENT

Price: $1100
www.iosafe.com

There are plenty of safes that can defend valuables from fire or flood, but what about data? Cloud backup is great, but it's now possible to bring hard-core protection to local network storage. **LINDSAY HANDMER**

The ioSafe 214 is a normal Network Attached Storage (NAS) device in many ways, and uses the excellent Synology operating system and mobile app. It has dual 3.5"/2.5" bays for up to 12TB of storage, a 1.06 GHz dual core CPU and 512MB of memory. There's also gigabit Ethernet, and you can add in wireless via USB.

But what about the flames and flood? Sadly ioSafe didn't let us actually subject the NAS to a burning house or throw it in a river. But if we had, ioSafe claims it can maintain data for up to 30 minutes at 843°C, in accordance with the ASTM E-119 standard.

To keep cool under fire, the ioSafe uses a special insulation with chemically-bound water molecules, all wrapped in a steel case. As the safe heats up, the water turns to steam and endothermically cools the NAS. For those who fear flood over fire, the 214 can handle a three metre immersion for up to 72 hours. Start dredging!

Of course this extra protection costs more than the average NAS, and an ioSafe 214 without pre-installed drives is a hefty $1100. But that's the price you pay for bomb-proof storage.

GETTING INSULATED

Thermal conductivity is the measure of how well a material transfers heat. Solids and liquids do it fast, while gases conduct more slowly. By trapping gas in a lightweight material (such as foam), convection currents are reduced. Aerogel is a material with a very low thermal conductivity - it's a type of foam made from substances such as silica, and is 98.2% air. Lightweight, and heat resistant.

The Foundation for the Advancement of Astronomy supporting excellence

The Foundation for the Advancement of Astronomy, established by the Astronomical Society of Australia, recognises excellence through the Society's activities.

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- **The Charlene Heisler Prize** for most outstanding astronomy PhD thesis
- **The Louise Webster Prize** for excellence by an early career researcher
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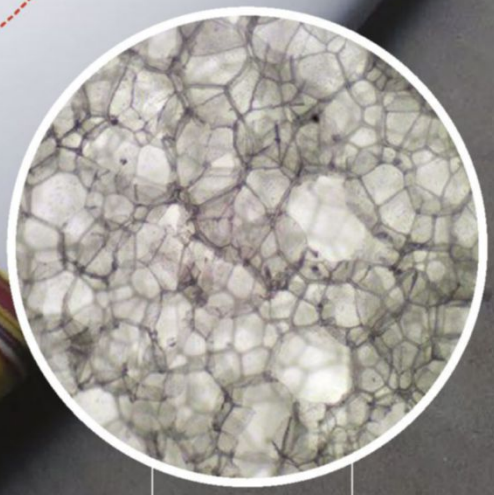
Materials

A Surfboard Made By a Rocket Scientist

Edison Conner, a former SpaceX rocket scientist and co-founder of Varial Surf Technology, tried for years to create a durable surfboard from aerospace material. In his eyes, the surfboard industry was ripe for disruption. Makers had clung to one manufacturing method for more than 50 years. For strength and flexibility, they created a spine from a strand of wood (known as a stringer) and glued it into a polyurethane foam cast. The cast was sanded and wrapped in fibreglass and resin. Conner and the other engineers at Varial tried something different. They replaced the wooden stringer with an extremely rigid foam similar to the type used in helicopter rotor blades and in rocket-propulsion systems. The foam is 30 per cent stronger, with seven times the stiffness (or modulus) of conventional foam. It's also 25 per cent lighter. That means surfers have a board that's easier to control and more durable.

BLAST OFF!



PEEK INSIDE
This 70x magnification of the Varial Foam microstructure reveals a tight cell structure made up of defined angles and polygonal shapes. The rigid structure of the foam makes surfboards lighter, stronger, and easier to ride.

Varial's chemists altered the polymers of the foam, producing high levels of crystallinity. The crystallised foam consists of structured, rigid lattice-like polymer chains. Crystallisation also makes cell walls thinner. That lets chemists pack more cells into a tighter, more-angular (or polygonal) cell structure. The structure is stronger and firmer than the looser, more-bubblelike cell structure of conventional polyurethane foam.

Aside from strength and durability, the new boards have more action (or buoyancy) in the water. "They are ultra light, which I love in smaller waves," says top pro surfer Shane Dorian, who won the Billabong Ride of the Year Award in 2015. "Ninety per cent of the time, I'm surfing head-high waves or smaller, so the responsiveness of the light boards is amazing."
MARK ANDERS

COURTESY VARIAL (2)

Speakers That Cut Through Noise

PROBLEM

Everyday speakers—whether they're in a smartphone, TV, or radio—scatter sound waves as soon as they leave the cone. A single wave can bounce off dozens of surfaces, slamming into other signals and degrading along the way, before reaching your ear in a muddled mess. Adding to this audio chaos, most midrange TVs only emit sound from rear or downward-facing speakers. So turning them up just doesn't help. Gamers and TV obsessives often turn to soundbars and directional speakers for relief, but even those don't offer a true high-fidelity fix.

SOLUTION

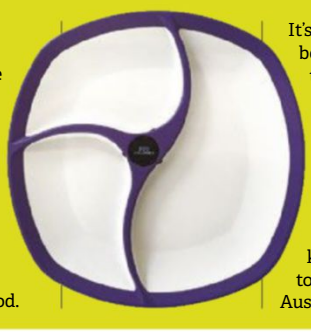
HyperSound Clear speakers aim sound waves directly at a listener using a tightly focused beam. It uses ultrasonic waves, which don't disperse as quickly or easily as standard sound waves. Embedded in that signal is high-fidelity audio with zero disruption. That means a movie's epic surround sound can be directed straight at your ear—just like a laser. HyperSound speakers were designed for the hearing impaired, and like hearing aids, they must be tuned by a doctor. However, in 2014, gaming audio giant Turtle Beach merged with HyperSound's parent company, raising hopes in the gaming world that laser-focused high-fidelity will be coming to Cheetos-crusted couches one day soon. **MICHAEL NUÑEZ**

LASER SOUND

Too Much Innovation

SMART PLATE, DUMB IDEA

We Westerners are a health-obsessed bunch, buying niche gadgets like wearable step trackers and sensor-filled adhesive strips to help maintain our fitness. Now to keep our outrageous consumption habits in check, there's the SmartPlate—a $200 Wi-Fi-connected dinner plate that automatically measures the kilojoules in every meal. The plate is equipped with three cameras embedded within the plate's meal dividers. The cameras work with an object-recognition smartphone app. Scales in each compartment determine portion sizes. The system can identify more than 400,000 different types of food.



It's accurate enough to tell the difference between wheat and flour pasta, and the app offers suggestions for what to add and subtract from your meals. The American Heart Association has even partnered with the company. Yet the SmartPlate isn't dishwasher or microwave friendly, which could deter the average glutton from forking over the cash. Because as we know, a dinner plate that can't be used to nuke Lean Cuisine is useless in most Australian homes. **LOREN GRUSH**

COURTESY SMARTPLATE

PHOTOGRAPH BY *Brian Klutch*

HEPA CAT!

UP Box
Price: $2695
URL: www.3dprintingsystems.com
Build volume: 255 x 205 x 205 mm
Layer resolution: 100 micron (0.1 mm)
Noise: 51.7 dB
Filtration: HEPA
Dimensions: 485 x 520 x 495 mm
Weight: 20 kg

A 3D printer that won't stink you out

Until now, desktop 3D printers have been useful but rather smelly devices. At its heart, a filament extrusion 3D printer is a hot glue gun - it melts a line of ABS plastic and smooshes it onto successive layers of a model, building up an object over several hours. That means a house or workshop full of the unmistakably smeel of "digital manufacturing" or, in layman's terms, burning plastic.

The UP Box encloses its build platform, control arms and print head in a rather attractive, well, box. A fan on the side circulates air through a HEPA filter, which all but eliminates that distinct, headache-forming odour.

A descendant of the excellent UP Plus, the UP Box has a 10 litre build volume and can churn out models up to 30% faster than its older brother. An external shell also means space for hardware controls. Users can pause, cancel and reset the printer without touching a PC. Just spool the job to the printer over USB, then disconnect and use the computer for something else.

Of course, despite maturing software, we're still in the infancy of desktop 3D printing. The UP Box is fast, but printing a model that takes up all the available space will still take more than 24 hours, especially at the finest resolution.

The UP Box can't compete with an industrial grade laser sintering device, but then, it doesn't pretend to. For a workshop, the UP Box enables rapid prototyping at a fraction of the cost of a CNC mill, and produces models that cost a few dollars in plastic.

And since you now don't have to smell that plastic all the time, the appeal of a tool like this is bigger, and boxier, than ever. **ANTHONY FORDHAM**

MUSIC BOX
The UP Box can indeed produce usable objects, like this electric guitar by Michael Tyson, of Adelaide. Since the guitar is larger than the printer's build area, he separated the model into several parts and assembled it later. With a hollow body, the result is a strong but very light guitar, exactly the way Tyson wants it.

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Next

EDITED BY ***Breanna Draxler & Jen Schwartz***

Lightning is incredibly powerful. One strike can contain 1,500 megajoules of energy—enough to power a 100-watt lightbulb for six months. But scientists know only the basics of how it works. Maher A. Dayeh, a heliophysicist at the Southwest Research Institute in San Antonio, aims to change that. In July 2014, his team triggered a bolt (shown here) by shooting a rocket trailing copper wire into a storm cloud. Fifteen microphones captured the sound waves created as heated air around the bolt expanded and then compressed. The result? The first-ever acoustic image of thunder. From it, researchers can infer how much energy went into forming the bolt, and how much it radiated as sound. Lightning is violent, Dayeh says. "Prediction and protection are almost impossible if we don't understand the process in the first place." **RACHEL FOBAR**

UNIVERSITY OF FLORIDA, FLORIDA INSTITUTE OF TECHNOLOGY, AND SOUTHWEST RESEARCH INSTITUTE

3.9

Estimated number of times, in millions, lightning strikes Earth every day, according to NASA's Marshall Space Flight Centre

As the particles in e-paper get smaller, resolution approaches that of traditional print.

COMIC SANS!

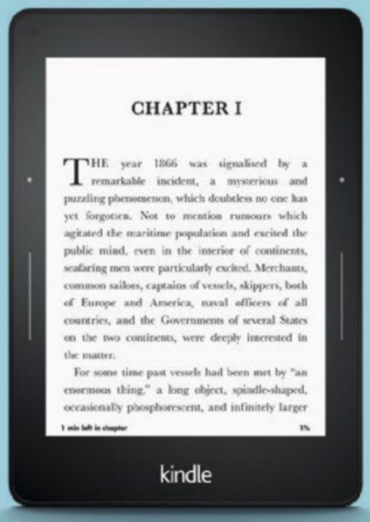
EXPLORING THE UNCERTAIN FUTURE OF ELECTRONIC PAPER

E-paper was invented in the 1970s, but it wasn't until more recently that it found widespread commercial application. The ultimate goal of e-paper is to match the appearance of normal ink on paper in all light conditions, while also being able to change what is displayed. Current electronic paper technology already offers a better contrast ratio than newspaper, and can be viewed in direct sunlight. Unlike LCD displays, one advantage of some e-paper varieties is the ability to maintain an image or text without an electric charge. So batteries last for weeks, not hours or days. Let's take a closer look between the lines.

LINDSAY HANDMER

So How Does It Work?

There are several types of e-paper, but the most common (used in e-readers) is Taiwanese company Prime View's "E Ink" - a type of electrophoretic display. The version in the Kindle Voyage is the E Ink Carta HD, which has a print-equivalent 300 ppi resolution. Tiny black and white particles with opposite charge are suspended in an oil between two plates with a gap of 10 to 1000 micrometres. The top plate is transparent, and individual sections (pixels) can receive an electric charge and attract or repel the black or white particles. By varying the charge to individual pixels, text is displayed. E Ink also has a version called Triton, which can display 4096 colours (though at lower resolution). The downside to E Ink? It takes the particles time to move, which means the displays don't work for video.



KINDLE VOYAGE

With one of the most advanced E-Ink screens available, the Voyage's 6-inch screen and high 300 ppi resolution means no individual pixels are visible and it truly does look like paper. What's more, the adjustable backlight of the Kindle is very even and makes extended reading very easy on the eyes. The Voyager is just 7.6mm thick, weighs 180 grams, has Wi-Fi, as well as a touch screen display and 4GB of storage. With the backlight cranked up it lasts a week or so of heavy reading, but at lower light levels is good for a month or more. We still think the OS is unnecessarily clunky for such a high end device, but gets the job done. Of course for those who already own the Kindle Paperwhite, it's probably not worth the expensive upgrade, but otherwise the Voyage is the best e-reader on the market bar none.

Price: $299
www.amazon.com.au

Tech Trend

TAKING THE GUESSWORK OUT OF FOOD

Between the reports of *E. coli*-tainted spinach and Listeria-laden ice cream, it's easy to become paranoid about what to eat. And rightly so: One in six of us will get a food-borne illness this year. But a number of new and soon-to-exist food-monitoring technologies can help keep your fridge contaminant-free, flag when something should be tossed, and tell you exactly what's on your plate.

HEATHER HANSMAN

1 MILK

Scientists at Peking University in Beijing created gold nanorod tags to put on food packages. They're designed to deteriorate at the same rate as what's inside. A colour change will indicate if a jug of milk has gone bad without having to take a whiff (or worse, a swig). "In principle, the tag can be used for any product that deteriorates over time and is packaged air-tightly: beverages, medicines, vaccines, and more," researcher Chao Zhang says.

2 MEAT

Use-by dates are static; people often throw away food that's still good—or eat food that's gone bad. Chemists at MIT created a thin sensor that can be put inside meat packaging. Its metal-lined carbon nanotubes carry a current that drops when it encounters amines, chemicals produced by decaying meat.

3 FISH

The FDA limit for mercury in tuna is 1 part per million. But levels vary from fish to fish. While most tuna companies sample a few fish per catch, Safe Catch made a quick test to biopsy every tuna at the dock, accurate to 0.1 ppm. "We're not OK using anyone's average," says Bryan Boches, Safe Catch co-founder.

4 OLIVE OIL

A 2012 study found that 60 per cent of olive oil sold to restaurants in California as "extra virgin" didn't meet USDA quality standards. Researchers at the University of California at Davis developed an enzyme-based electrochemical biosensor that ferrets out aldehydes indicative of less-pure oil.

5 FRUITS AND VEGETABLES

When food-borne illness breaks out, it can take months to follow the bug back to the source. A food-safe spray called DNATrax, developed at Lawrence Livermore National Lab, uses DNA extracted from plants to create a traceable molecular bar code that's unique to fresh fruit and veg's farm of origin.

33

Percentage of fish sold in US shops and restaurants that were mislabelled, according to a 2013 Oceana study

A Food Label Just for You

Frustrated by one-size-fits-all nutrition facts, designers at New York University decided to intervene. "We want food labels for consumers rather than a compromise between government, food lobbies, and big food companies," says Sam Slover. Their app, called Sage, uses info like your weight and activity level to create personalised labels for food. If you've got a peanut allergy, it can flag risky products. If you splurge on cheesecake, it'll tell you how many minutes you'll have to spend on the elliptical to burn it off.

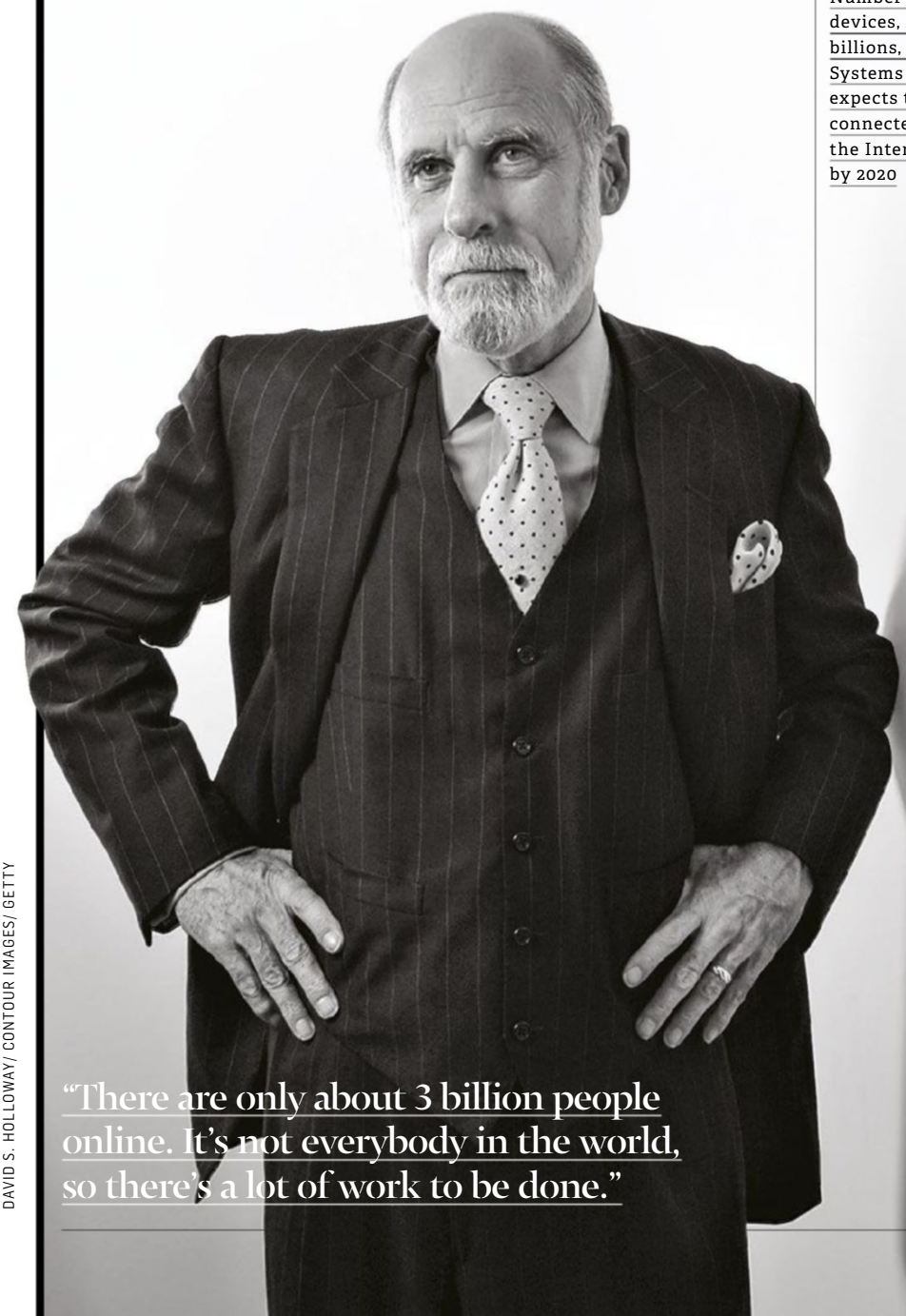
FOOD STYLING BY SUZANNE LENZER

PHOTOGRAPH BY Sam Kaplan

Vint Cerf

On the Interplanetary Internet

The Internet has changed a lot over its 30-something years. That terrible dial-up noise is gone; the Ethernet cord has been cut; Tinder happened. What's next? If anyone knows, it's Vint Cerf, Google's vice president and chief Internet evangelist. He is considered a "father of the Internet" for developing the protocols that run it: breaking information into packets, sending them into cyberspace, and reassembling them onto your screen. Cerf has watched his baby grow up and get smarter. Now he's envisioning how it will mature in the coming decades.



"There are only about 3 billion people online. It's not everybody in the world, so there's a lot of work to be done."

DAVID S. HOLLOWAY/ CONTOUR IMAGES/ GETTY

"

50

Number of devices, in billions, Cisco Systems Inc. expects to be connected to the Internet by 2020

When we turned on the Internet in 1983, having a powerful computer in your pocket was science fiction. But the Internet has evolved beyond even phones to encompass smart objects that talk to each other and to you. Those devices—called the Internet of Things—now need standard protocols that allow connected products from different companies to work as an ensemble.

Soon cars, buildings, cities, and people will have sensors and software that track resources, respond to crime, or take constant vital signs. In that environment, machine learning will become increasingly important—not insane robots but systems much smarter than today's Google searches.

Once we've connected everything to everything else, safety and privacy will be big challenges. It's impossible to stop abuse, but we have to be able to detect it. We need to develop better security and authentication technology, as well as better international agreements to prosecute cross-country cybercrimes.

The Internet, though, will extend beyond political borders, and even beyond Earth. A prototype Interplanetary Internet already stretches between our planet and the International Space Station. Astronauts use it to communicate with Earth. The Interplanetary Internet will evolve and expand as old spacecraft become nodes in its backbone, helping pass along signals.

To handle the delays and disruptions that occur in space, we need robust protocols. I helped develop the new "bundle protocol," which assumes the link will break occasionally. When that happens, it stores the packets of data and waits to send them until the connection becomes secure again. The United Nations is in the process of adopting it as the standard that will support manned and robotic exploration into deep space.

We initially designed the Internet to be a network of networks that could expand over time. And so it has. And so it will."

AS TOLD TO SARAH SCOLES

Lab-Grown Diamonds to Keep Electronics Cool

A clear, sparkling diamond is rare. That's part of its appeal. Those mined today formed billions of years ago. But a new method can grow gem-quality diamonds on demand in just three months. They're identical to their natural counterparts and cost 30 to 40 per cent less. That's promising for anyone in the market for an engagement ring. And it bodes well for the future of electronics too.

REBECCA HARRINGTON

72 Global diamond jewellery sales, in billions of US dollars, per year

1

Global demand for diamonds is currently on the rise, thanks in part to a growing middle class in countries such as India and China. But it's been a decade since a large diamond mine has been discovered. By 2019, demand is projected to outstrip supply by 5 to 6 per cent.

2

Luckily, diamonds can also be made in a lab. In the 1950s, scientists first created diamonds by replicating the intense heat and pressure that forms them underground. The stones tend to be discoloured and small (in some cases just a powder), but they retain a natural diamond's defining properties.

3

Diamond is one of the hardest known materials. It can withstand high levels of radiation and doesn't trigger an immune response. This makes it useful in construction, nuclear engineering, and medicine. In 2013, industry used about 1,500 tons of diamond, 99 per cent of which was lab-grown.

4

To make purer gems, diamond-grower Ila Technologies refined a process called chemical vapour deposition. In a vacuum chamber, they shower a fingernail-thin diamond "seed" with microwave rays and methane and hydrogen gases. These build up layers of carbon bonds.

> "If anyone says they can tell the difference without a machine, they're lying."
>
> —**ARIEL BARUCH**, JEWELER AT DIAMONDS BY ISRAEL STANDARD INC., WHICH SELLS LAB-GROWN DIAMONDS

5

In March, Ila opened the world's largest diamond-growing facility in Singapore. It's capable of cranking out more than 300,000 carats a year, using half the energy of diamond mining. Plus it has far less environmental impact. To the naked eye, the diamonds are indistinguishable from natural ones. But they'll still be a tough sell for jewellery, where lab-grown make up less than 1 per cent of the market. "They're seen as inauthentic, no matter that they are objectively identical," explains Ravi Dhar, director of the Centre for Customer Insights at Yale University.

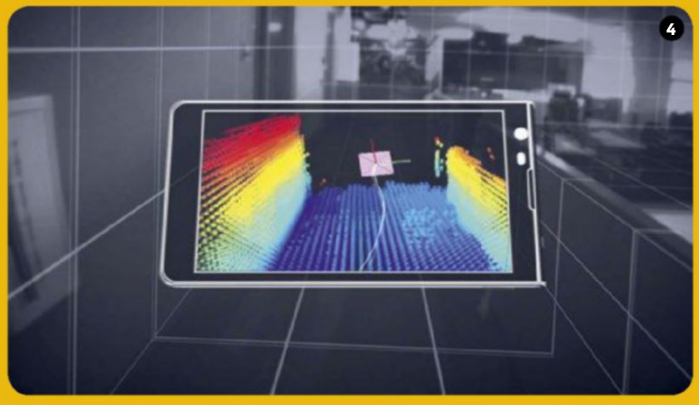
6

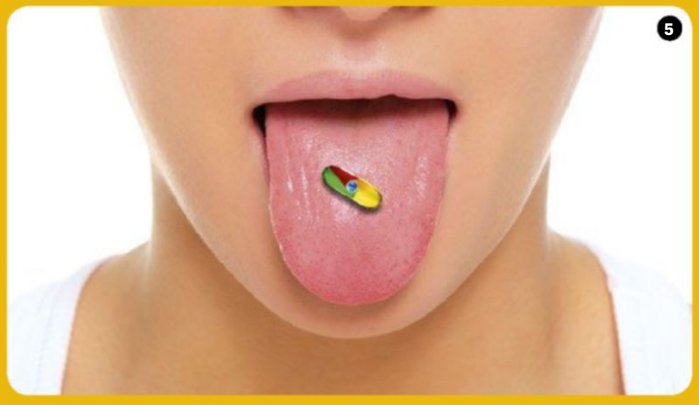
Diamond's unsurpassed thermal conductivity makes it an ideal heat sink for electronics. It transfers about twice the heat and can carry more current than the silicon usually used in semiconductors. Ila is working to grow diamond plates that will enable smaller, more-powerful devices that don't overheat. "It will take time," says physicist Devi Shanker Misra, who invented Ila's technique, "but I hope that it will replace silicon."

COURTESY PURE GROWN DIAMONDS

FIVE LITTLE-KNOWN GOOGLE PROJECTS THAT COULD CHANGE THE WORLD

From driverless cars to the ARA modular phone, Google is dedicated to fun and exciting side projects. But what about the lesser known ideas? Here are our top 5 projects with the potential to change the world. **LINDSAY HANDMER**





1 Project Wing
Not just a marketing stunt from Pizza Hut or Amazon, Google is actually testing delivery drones. Rather than buzzing around crowded city areas, the drones are designed for remote areas where normal delivery systems are slow and inefficient. Project Wing uses custom electric drones that can transition from long distance fixed wing flight to vertical take-off and landing. Delivery payloads are actually winched down to the ground and released, rather than the drone landing.

CHALLENGE: Regulation.
LIKELIHOOD:

2 Google Contact Lens
While this sounds like an amazing shrunken down version of Google Glass, the smart contact lens project is actually designed for medical monitoring. The smart contact lens has a tiny wireless transmitter coupled up to a glucose sensor, to help diabetics monitor blood sugar levels. But it could do so much more. Power is sent to the lens via RFID - though other ideas such as LED warning lights for low or high blood sugar levels are being tinkered around with.

CHALLENGE: Approval, human trials, power source
LIKELIHOOD:

3 Project Loon
Two thirds of the world doesn't have access to the internet - something Google wants to fix, fast and cheap. But building 4G towers or rolling out fibre isn't cheap or fast in rural or remote areas, so the Google boffins have a more ambitious plan. They want to build a wireless network with an array of high altitude balloons. Testing is already underway, though one failure has already seen a Loon balloon crash into power lines in the US. That probably has a negative effect on Netflix.

CHALLENGE: Weather, borders, regulation.
LIKELIHOOD:

4 Project Tango
Google's venture into real time 3D vision mapping and augmented reality, Tango is designed to bring motion tracking, depth perception and area learning to mobile devices. This set of skills comes naturally to humans, but for a computer they are among the hardest tasks. Tango could help create more intelligent and spatially aware robots - which means they will be safer to work alongside - as well as create a huger new market in awesome augmented reality games. Just like in Neuromancer!

CHALLENGE: Application, testing
LIKELIHOOD:

5 Nanoparticle Platform
Straight out of the Google X research labs, this project is a smart pill that can be swallowed and then used to detect disease - from inside your body. It uses magnetic nanoparticles that are combined with special antibodies and proteins that can identify and latch onto other molecules. The particles can be directed to certain parts of the body, then collected to see what they have discovered. It's weird, but beats having chunks cut out of your body for a biopsy.

CHALLENGE: Safety, human trials, transmission system
LIKELIHOOD:

SPECS

Combat Range 1500 km, depending on payload

Payload Four crew and up to 14 troops, or more than 5400 kilograms of cargo

Speed 280 knots, or 515 kilometres per hour

THE MOST VERSATILE AIRCRAFT IN THE SKY

Future conflicts will favour faster, nimbler military forces—think precision strikes and special ops. "The military needs assets that allow them to project their combat power more rapidly," says Keith Flail, a program director at Bell Helicopter. It needs an aircraft that can hover for tactical manoeuvres but also conquer the "tyranny of distance."

The V-280 Valor (sic) could do just that. Its tilt-rotor design allows the craft to take off and land vertically, like a helicopter, or pitch its rotors forward to fly horizontally, like a turboprop plane. It stands to be safer and more agile than its clunky cousin,

ILLUSTRATION COURTESY BELL HELICOPTER

"Our nation and our service members should never have to fight a fair fight."

—**KEITH FLAIL**, DIRECTOR OF THE FUTURE VERTICAL LIFT PROGRAM AT BELL HELICOPTER

the V-22 Osprey. With twice the speed and combat range of the Army's current workhorse, the Black Hawk helicopter, the V-280 could vastly extend the reach of ground forces.

Bell Helicopter's design is vying for the top spot in the US Army's Future Vertical Lift program, which aims to develop a family of next-generation rotorcraft. If chosen, the V-280, or something like it, could be in the sky by 2030. **CLAY DILLOW**

1
STREAMLINED NACELLES
Unlike the larger, less-agile V-22 Osprey, the V-280's rotors tilt while its engines and gear boxes remain stationary. This eliminates moving parts, and keeps the engine housing out of the way to make entering and exiting the aircraft easier and safer.

2
CARBON ROTOR BLADES
The first-ever all-carbon tilt-rotor blades make the V-280 light and manoeuvrable, particularly when operating at low speeds. They also boost stability in crosswinds and can reduce propeller downwash, which affects cargo loads tethered to the aircraft's belly.

3
FLY-BY-WIRE CONTROLS
In conventional helicopters, the pilot spends a good deal of effort simply keeping the aircraft stable. The V-280's advanced fly-by-wire controls allow flight computers to do much of that work, which is especially useful when transitioning between its two flight modes.

4
STRAIGHT WING
In contrast to swept wings, which form the V-shape of most jet profiles, Bell's engineers designed a straight wing with a single drive shaft that runs its length. This enables the craft to operate both rotors via a single engine if one loses power.

5
SITUATIONAL AWARENESS
A head-up display on the visor of the pilot's helmet stitches together footage from six cameras on the outside of the craft. This allows the pilot to essentially see through the walls to what's beneath, beside, or behind the plane. As Flail describes it: "It's kind of like flying in Wonder Woman's [invisible] jet."

6
MODULAR PAYLOAD BAY
The payload bay could hold weapons systems that turn the V-280 into a fast-moving gunship. Close air support weapons could be extended from the bay doors during combat and articulate back into the aircraft during cruise flight to reduce drag.

58 Dollars, in billions, spent on pets in the US in 2014, according to the American Pet Products Association

Robot Pets Have a Leg Up on Fido

Humans have been bonding with domestic animals for tens of thousands of years, but Jean-Loup Rault, an animal scientist at the University of Melbourne, thinks new companions are coming: robot pets. Just as digital technologies have altered how we interact with each other, they could soon do the same for us and animals.

This may not sit well with pet-lovers. A plastic dog is hardly as cuddly as a Pomeranian. But Rault argues the robot variety has a lot going for it: "You don't have to feed it; you don't have to walk it; it won't make a mess in your house; and you can go on holidays without feeling guilty." Plus mechanical animals could open up pet ownership to people with allergies, mobility issues, or tiny flats.

The biggest selling point might be that robot pets combine the utility of a machine with the companionship of an animal. Dan Goldman, who works with biomechanical robots at the Georgia Institute of Technology, imagines what one might look like: "It'll be a dog that can read your emotions and respond. It'll be a snake that can slither under your bed to find toys." One day we might even be able to transfer a robot pet's memory to an upgraded model to make it a lifelong companion.

That's convincing on a practical level, but it doesn't address whether humans can actually bond with machines. Studies suggest we can: When companion robots like Paro, the sensor-studded interactive seal, have been given to nursing-home residents, they can improve moods, combat loneliness, and increase social engagement. "As humans, we're eager to bond with things," says Bill Smart, who studies human-robot interactions at Oregon State University. "People give their cars names. Kids give their stuffed animals back-stories." So too with robots. When Sony shut down the last tech clinic for its discontinued dog Aibo in March 2014, owners in Japan held funerals.

In the end, what might hold people back from adopting robot pets could be as simple as their frame of reference. For those who grew up with living, breathing, slobbering pets, the mechanical kind might not do. Neither Rault nor Smart wants one. But for kids who constantly engage with smart technology, extending that connection to a robot dog or dino just might be the next logical step.

BREANNA DRAXLER

A BRIEF HISTORY OF ROBO-PETS

1996 ~~Tamagotchi~~
1998 Furby
1999 Aibo
2001 Paro
2002 Roomba
2005 iDog
2006 Pleo
2014 MiP
2015 Ringo

"At some level you know it's a robot. But as you interact with it, you'll probably find yourself doing things that you'd do with animals." —**BILL SMART,** ROBOTICIST AT OREGON STATE UNIVERSITY

COURTESY SONY

Anthony Fordham is the editor of the Australian Edition of Popular Science and lives in an urban area where he can't see any wind turbines. He sure can hear the coal trains come through at 2:30am, though.

Why do so many of us hate the wind?

COLUMN BY ANTHONY FORDHAM

You have to believe me when I say I REALLY didn't want to talk about wind turbines again this issue. But then the government went ahead and "banned" the Clean Energy Finance Corporation from investing in new wind power technology. Because if there's one thing we know the current government stands for, it's that wind power is terrible and turbines are "visually awful" and who cares if this infrastructure is cheap and fast to build - don't you understand? Can't you SEE? The wind doesn't blow all the time! So wind turbines are stupid!

Sorry if that comes across as glib, but I've spent the last couple of weeks trying to figure out why so many people hate wind power so much. The people who now have giant turbines on the horizon where once there were only rolling brown fields, maybe that's understandable. The people who honestly believe these things are making them sick, that at least makes logical sense. But the person who lives hundreds of kilometres away from the nearest wind farm... why do they suddenly care about the engineering behind their always-on electricity?

I struggle to think of another technology that gets so much hate. Mention wind turbines in the right sort of company (or company that's sort of on the right), and people will pipe up to insist this technology is FUNDAMENTALLY FLAWED and that ANYTHING is a better alternative. Solar thermal, geothermal, hydro, even nuclear gets love in this debate. Anything but wind turbines!

There's a certain kind of gentleman - a smart guy, tinkerer, inventor, builder-of-his-own-car/boat/generator - who writes in to magazines like *Popular Science* to take us to task for not exposing wind turbines as the giant unworkable scam they so obviously are.

I am sure the psychology behind this is complex, because the fact is - as I've stated before - that big companies build wind farms and extract both money and electricity out of them. They aren't excessively subsidised, there's no Ponzi-scheme or promise of a return some time in the year 2050. Real returns come quickly. Wind turbines are easy to build and they make power.

But if you SAY this to one of these almost-literally Quixotic wind-haters, they will email you dozens of links to other anti-wind activists who insist every set of pro-wind numbers - from stated capacity to claimed generation, projected up-time, costs and time-to-profit - are falsified. Outright lies to make a non-functional technology look good.

Surely the reason behind this isn't as simple as the fact that the wind doesn't blow all the time? The anti-wind guy (and it's always a guy) always starts his argument with the way the wind ebbs and flows. Some people even think wind turbines have to be "kept spinning" when there's no wind (or they explode? I dunno) and this means they are a net CONSUMER of fossil-fuel sourced electricity. This kind of argument makes my head hurt, and it's not from those turbines on Lake George.

When you research the pro- and con- camps on wind, you find all kinds of crazy stuff. Doubling of input costs to make wind look bad, weird assumptions about the weather, claims that there will be less wind or that the cost of attaching the turbine to the grid wipes out any benefit.

Bizarrely, the kind of people who say we don't need desalination plants because it's ridiculous to live in fear of a 1-in-10,000-year drought, will also say that relying on wind is dangerous because what if a freak weather system comes along and plonks down on top of your wind farm so there's no wind for weeks?

Maybe the whole problem is that the average armchair engineer finds it easy to understand the limitations of wind power. Yet he also remains blind to the benefits of it. Perhaps though the biggest issue is iconography. Nothing symbolises a "Green agenda" better than the looming, semi-religious silhouette of a wind turbine against the horizon. Half cross to bear, half invading tripods from War of the Worlds.

Sure, some companies will install bad wind farms, some farmers will get ripped off, I'm not trying to say this industry is perfect. But it's a lot less *imperfect* than coal. Wind power is an inevitable part of the future energy mix. If you oppose this technology, you really are tilting at windmills.

27

Percentage of electricity in South Australia produced by wind farms, as of August 2014.

Source: Government of South Australia

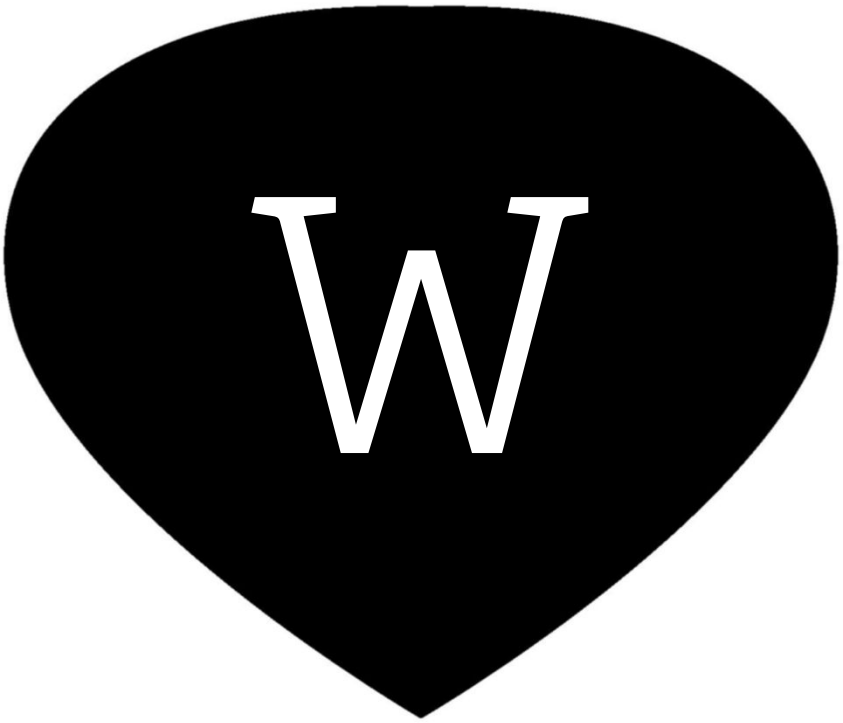
World View Experience says it will take passengers to the stratosphere by 2017.

Wish You Were Here

You don't need a rocket to get to space. There's a slower, gentler trip in the works—and it comes with a cocktail.

By Kalee Thompson

ILLUSTRATION BY WORLD VIEW EXPERIENCE



A helium-filled balloon will carry Zero2Infinity's tourist pod to 40 km above Earth.

When Alan Eustace lifted off into space from the New Mexico desert this past October, it was with a quiet whoosh, and a slight jostle of his harness. The 57-year-old computer scientist from Google—outfitted in a 117-kg pressurised space suit—dangled solo from a polyethylene balloon as thin as a dry-cleaning bag. As the balloon rose steadily into the air, the small bubble of helium inside began to expand, and as it rose, the balloon changed shape. At first it undulated skyward, limp and oblong, like a jellyfish. Then it grew into a soft, bulbous teardrop. Finally, as Eustace neared his destination, 40 km above the planet's surface, it became perfectly firm and rounded, a shimmering object the size of a football stadium. Beyond it spanned the blackness of space. Beneath lay what has long drawn humans to these heights: a soul-altering view of the curvature of Earth.

To most, Eustace's flight seemed the antithesis of space travel, which since the dawn of the space age has been synonymous with the fiery roar of a rocket. The first private companies racing to take paying customers to the edge of space—Virgin Galactic, XCOR Aerospace, and Blue Origin—promise the kind of thrill ride experienced by astronauts. But there's an alternate space race taking shape, one whose selling point is slow and serene. A handful of startups are rushing to pioneer tourist trips to the stratosphere beneath enormous balloons. "Balloons are a beautiful mechanism for taking off," Eustace says. "You're perfectly balanced; it's perfectly quiet; there's no vibration as you're going up." Once at altitude, passengers will drift with the winds as they peer from the comfort of a pressurised capsule. After a few hours, they will glide back to Earth beneath a wing-shaped parafoil.

For one company, Eustace's StratEx mission was proof of principle—a "one-man version" of stratospheric balloon tourism, says Taber MacCallum. He and his partner, Jane Poynter, headed Paragon Space Development Corporation, which managed Eustace's flight plan and built his life-support system. The couple then started World View Experience, a Tucson, Arizona, operation that intends to be the first to take customers to 100,000 feet, or 30 km, for $75,000 a head. They're aiming the maiden flight for 2017.

"YOU CAN TAKE YOUR PARENTS AND CHILDREN. IT'S GOING TO BE THE ULTIMATE FACEBOOK STATUS UPDATE: THE ENTIRE FAMILY IN SPACE."

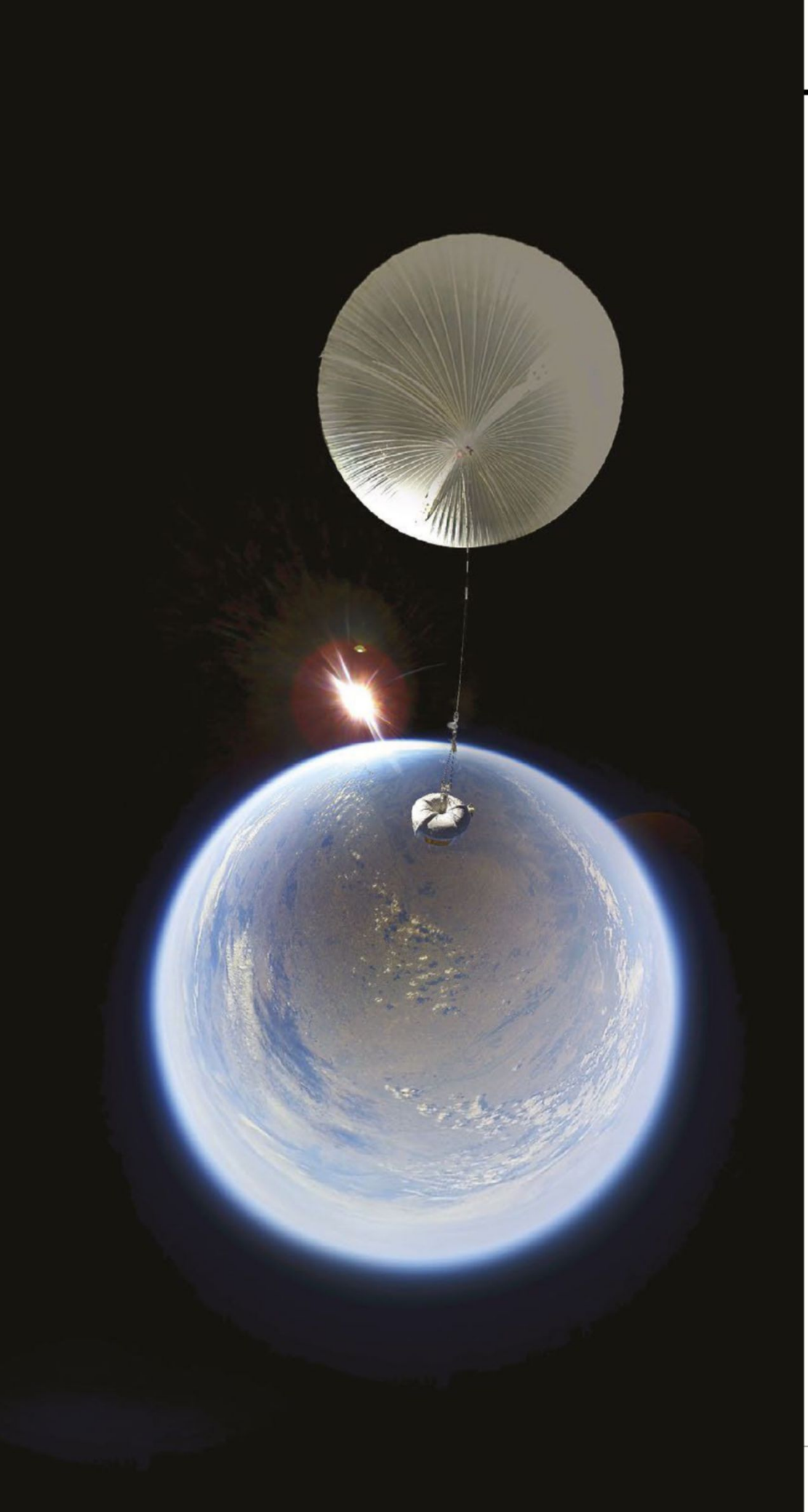
Zero2Infinity in Barcelona and Chinese startup Space Vision will also fly passengers in the next few years. They are selling tickets from US$80,000 to US$125,000. The fees are steep, but not when compared with $250,000 for a seat on Virgin Galactic's suborbital spaceplane, or the $50 *million* broker Space Adventures charges for a weeklong jaunt to the International Space Station.

Altogether, balloons could offer a more inclusive form of space tourism. "It's a very slow, gentle ride up and a slow, gentle ride back, and you get to be up there for hours," MacCallum says. Without the gravitational forces of takeoff and landing, the flight comes with minimal health restrictions. Motion sickness is unlikely to be an issue. Couples might get married in near-space, or celebrate a grandparent's birthday. World View is already taking $7,500 deposits to secure seats on future flights. "We've had families sign up and buy the whole capsule," MacCallum says. "You can take your parents and children. It's going to be the ultimate Facebook status update: the entire family in space."

In 2002, two years before Scaled Composites claimed the $10 million Ansari XPRIZE for private spaceflight, Zero2Infinity's founder, José Mariano López-Urdiales, wrote a paper for grad school entitled "The Role of Balloons in the Future Development of Space Tourism." He calculated stratospheric ballooning could be a US$10 billion-a-year industry. The technology required to send tourists to such altitudes—the balloons, the helium fuel, the pressurized capsules—had been well proved, he noted. It's also relatively affordable and easy to procure.

Rocket flight, in contrast, is both costly and difficult. The public got a stark reminder of that in 2014, when Virgin Galactic's *SpaceShipTwo* exploded over the Mojave Desert, killing a test pilot. "When you light a rocket, 10,000 things can happen, and only one of them is good," says Michael López-Alegria, a former NASA

ILLUSTRATION BY ABACO DIGITAL/IGNACIO FERRANDO/ZERO2INFINITY



astronaut who recently signed on to advise Zero2Infinity. With balloons, he says, "you're not going as fast, you're not going as high, you're not putting as much energy into the system."

Whereas Virgin Galactic plans to soar to nearly 330,000 feet—just past the 100-km mark widely considered the threshold of space—balloons will top out at just over 100,000 feet (30 km). The difference is not as significant as it might seem. "At that altitude, you've got 99 per cent of the atmosphere underneath you," says former space-shuttle commander Mark Kelly, now the director of flight operations for World View. "You're essentially in a vacuum. You're in the blackness of space." He agrees with López-Alegria that balloons pose less risk. "If you can take the complexity out of getting people to that vantage point," he says, "at least theoretically you can do it a lot safer."

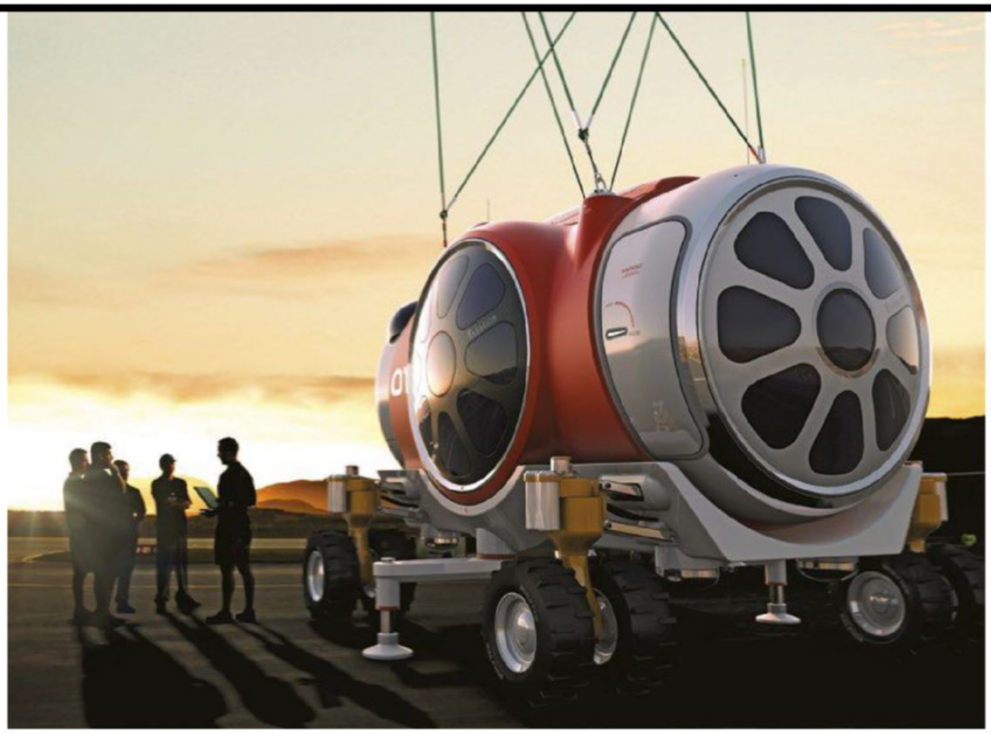
The straightforward nature of balloons has always appealed. In fact, they powered the very first space race. In 1931, a balloon lifted Auguste Piccard and Paul Kipfer to the stratosphere in a pressurised capsule, a feat described in the August 1931 issue of *Popular Science* as an "adventure [that] surpasses fiction." As we wrote then: "Seventeen hours later, after being given up for dead, they returned safely from an altitude of more than 52,000 feet, almost ten miles [16 km], shattering every aircraft altitude record." New records continued to be set and broken through the 1950s. And then in 1960, US Air Force Capt. Joe Kittinger rose to 102,800 feet (31.3 km). His record stood for 52 years—until October 2012, when Austrian skydiver Felix Baumgartner ascended to 128,100 feet (39 km). Eustace passed Baumgartner's milestone two years later, reaching 135,890 feet (41.4 km).

Like Kittinger and Baumgartner before him, Eustace floated briefly in the stratosphere, taking in a view he calls "marvellous." As he remembers now, "It's beautiful watching how the light diffuses through the different levels of the atmosphere." And then Eustace released his balloon and fell back to Earth protected by only his space suit. His body reached 1,322 km/h, exceeding the speed of sound,

before the atmosphere thickened and a parachute deployed to slow his descent. To succeed at a new form of balloon-based tourism, companies will have to figure out a way to get customers not only up, but also down.

A **balloon ride** to the stratosphere will be a three-part act: the launch, the pleasant cruise at altitude, and the trip back to Earth. The first part should be straightforward. For its commercial flights, World View plans to use a balloon that's more than 120 metres in diameter—the same size as the one that carried Eustace. (Though it will be towing a 4,000-kilogram tourist capsule, the balloon doesn't need to ascend as high.) Because of the StratEx mission, World View's team has practice launching it.

Zero2Infinity has been launching unmanned balloons as a test for two different business ventures: stratospheric tourism and a commercial satellite delivery system. It's also designed a doughnut-shaped craft that it plans to adapt for both applications. The version that will carry tourists, called a Bloon, will be big enough to hold two pilots and four passengers. The company has so far built a prototype half that size and used it to send a small humanoid robot to near-space. ("In the old days it would have been a dog or a monkey," López-Urdiales says.) Equipped with cameras and sensors, the robot helped the engineers at Zero2Infinity understand the passenger experience. When the robot looked through the windows, which ring the outside wall, reflections obscured the view. As a result, the window's position will likely change, López-Urdiales says.



Passengers in World View's capsule (here, a mock-up) will have Internet access for uploading photos.

THE CAPSULE WILL HAVE A BAR

AND A BATHROOM, AND THE CREW WILL DOUBLE AS BARTENDERS AND TOUR GUIDES.

World View envisions an oblong capsule with viewing ports on each side. About the size of a minibus, it will have seats for six passengers, a pilot, and a crew member. Passengers will need to be buckled in for liftoff and landing, but most of the ride will be a casual sail, like a skiff gliding across the surface of a lake in a light breeze. Although winds 30 km up can reach 210 km/h, the high speed won't be perceptible. That's because Earth, which provides the only reference point, will appear to barely move. The capsule will have a bar and a bathroom, MacCallum says, and the crew will serve the drinks.

Both MacCallum and López-Urdiales agree that balloon tourism should provide a shirtsleeve environment throughout the flight. "The goal is to have no training, no space suits," MacCallum says. "This will be very similar to a commercial-airline flight, where you're given a briefing and off you go." But outside the pressurised capsule, the environment is lethal. Exposure would mean near-instant death. For that reason, the companies will have to decide how to balance comfort with safety in the event of an emergency.

"At the very least the pilot should be wearing a space suit," says Art Thompson, whose aerospace company, Sage Cheshire, built the pressurised capsule that carried Baumgartner to the stratosphere. "If you have an issue with the craft, you want the pilot to be able to be in control." The smartest strategy,- Thompson says, might be to convince tourists to wear suits too. Of course, space suits require training, and looking like an astronaut might not have as much appeal as being able to easily sip a cocktail or hold your kid's hand 30 klicks up. At this point, the companies just seem to be banking on their ability to get the capsule down if a problem is detected—no awkward garments or free-fall skills required.

The third phase of the journey, the return, will be the most difficult. So World View is now heavily focused on refining the parafoils that will deliver the capsules to Earth. "We want to have enough cross-range to be able to fly to an airstrip and gently land in a predetermined place," MacCallum says. "Doing that from 100,000 feet has never been done." Because the air at that altitude is so thin, many doubted it was possible. But the company has now flown unmanned parafoils from 30 km three times, each with a payload of about 45 kg. This year they plan

Physicist Auguste Piccard prepares to make hissecond balloon trip to the stratosphere in 1932.

FROM TOP: COURTESY WORLD VIEW EXPERIENCE; SSPL/GETTY IMAGES; FACING PAGE: COURTESY WORLD VIEW EXPERIENCE; COURTESY XCOR AEROSPACE

The Ride of Your Life

Space tourism will offer different experiences, depending on the cost of a ticket—and your taste for adventure. Here are two.

STRATOSPHERIC BALLOON

CARRIER: World View Experience

COST: $100,000

1 You board the capsule a couple of hours before dawn. The monstrous polyethelyne balloon that will lift you into the stratosphere towers in the air above. You choose a seat, but it doesn't really matter—they all swivel for a 360-degree view. After a five-minute briefing from the pilot, a former astronaut, the craft begins to rise.

2 The ascent is slow and steady, averaging about 17km/h. You barely feel it. As the helium inside the balloon expands, the shape transforms from a long, thin teardrop into a taut, rounded object. After an hour and a half, the balloon reaches 100,000 feet (30 km). You're free to walk around, use the restroom, or have a cocktail.

3 The craft drifts at this altitude. Its movement is gentle; the pilots refer to it as "sailing." They point out constellations and planets. Soon, the sunrise begins, illuminating the winding scar of the Grand Canyon 30 km below. Your pilot describes his own first experience with the so-called overview effect, the emotional shift in perspective that comes with gazing down at Earth. You pull out your phone and snap a picture, a selfie from the stratosphere.

4 After two hours, the pilot vents helium from the balloon to begin a descent. He then sets the balloon free, leaving the capsule hanging from a 30-m-wide parasail. It begins a directed glide. The wind pushed the balloon several hundred kilometres, and the parafoil will make up most of that distance on the return. The pilot's attention is focused on flying—this is the part of the trip he has trained for. The sensation is similar to being in a small, perfectly silent aeroplane. The swooping descent takes less than an hour, delivering you to an airfield four to five hours after you lifted off.

ROCKET-POWERED PLANE

CARRIER: XCOR Aerospace

COST: $135,000

1 You're secured into the passenger seat of the Lynx suborbital spaceplane, seconds from takeoff. You've passed your medical examination and spent two days training, learning tricks of the trade like shallow breathing to handle G-forces. Though the cabin is pressurised, you're wearing a pressure suit as backup. Air traffic control speaks through the radio in your helmet. "Cleared for takeoff. Three...two... one. Ignition."

2 The four rocket boosters in the plane's tail ignite, and the spacecraft roars off the runway. In 60 seconds you're at supersonic speeds, although from inside the cockpit you can't really tell. All you know is that you're going fast. You tilt back as the Lynx's nose rises, hurtling up through the atmosphere at an 75-degree angle. The altimeter clicks upward toward 330,000 feet (100 km), and the surface of Earth fades away.

3 Then, suddenly, it's just you, the pilot, and the blackness of space. Gravity doesn't seem to tug at your arms anymore, and you can see far beyond the curvature of Earth. You're weightless. The pilot adjusts the boosters to keep you on track, but this is your time to take in the incredible view.

4 After about five minutes, you begin to descend. The force of gravity returns, stronger than before. Re-entry is swift and hard. At its greatest, you feel the pressure of four times gravity's pull. The force lessens as the Lynx grips the atmosphere, and soon you're at cruising altitude. The spacecraft feels more like a commercial plane now, and the landing gear lowers as you make a final approach. After your 30-minute ride you touch down, back where you started. It's an extreme sport, awesome... but maybe not for everyone.

to step it up by a factor of 10, testing the GPS-guided system with a 450 kg payload over the south-western United States. "Assuming all that goes well, by the end of this year we'll be at full-scale flight with a [four tonne] capsule and commensurately large parafoil," MacCallum says.

One focus of Zero2Infinity's upcoming flights, also scheduled for this year, will be to test the high-speed telemetry link that will beam live video down from the capsule. Another arm of the company focuses on developing huge parafoils that could act as rescue systems for traditional aircraft. While they would be much larger than the ones eventually used for tourist capsules, having two applications for the technology accelerates the development while reducing the risk and cost, López-Urdiales says.

During tourist trips, the parafoils will be guided at least partially by pilots, and so both companies will need to conduct manned test flights. Some of those test pilots will likely be former NASA astronauts. Kelly says that people who have flown the space shuttle, like him, won't be starting from scratch. The shuttle was also a glider that made an unpowered descent. Similar to a parafoil and a capsule, it encountered a lot of drag for the amount of lift it could create. To train, Kelly will spend time this summer jumping out of aeroplanes and learning to fly a small parafoil. Though he's in charge of assembling a team of World View pilots, he expects that he'll complete at least some of the early manned test flights himself, as well as serve as pilot on the first commercial trip to the stratosphere.

The simplicity of World View's vision—at least compared with rocket flight—is what attracted Kelly to the project, he says. Potential tourists will likewise be drawn for the same reason, in hopes of experiencing the same payoff. Before he went to space for the first time, Kelly was sure the most remarkable thing would be floating in zero gravity. "That wasn't the case," he says now. "The biggest takeaway is looking at the planet with your own eyes—a round ball just floating there in the cosmos."

THE DAY DISPLACEMENT DIED

Extreme circuit racing used to be all about giant engines. V10s, V12s, even V16s. Litres and litres of displacement, sucking down litres and litres of fuel on every lap. All that's changed. In 2015, the *24 Heures du Mans* – the race we call Le Mans – wasn't just a showcase of driving skill. It was a showcase of engineering. Fast cars with tiny engines, packed with clever energy recovery technology. **ANTHONY FORDHAM** was there, to observe our inevitable motoring future.


DMG MORI
14
DMG MORI
DMG MORI

FOR SOME REASON, the mood in the Porsche garage reminds me of musical theatre. Then I get it: the drivers are the actors, out there on the stage. The mechanics and engineers are the stagehands and AV crew. The high ranking Porsche executives sitting in front of the big monitors are the directors. Everyone is somehow simultaneously tense and relaxed. After 380-something laps and 22 hours, the team has slipped into routine.

Pit stops become a set of almost instinctual moves: fuel the car, peel back the plastic on the windscreen for an 'instant clean', swap tyres if necessary, occasionally change drivers. It all happens with seamless German efficiency. No one shouts. No one falls or jams their hand in a door or drops a tool. Activity is focused, fast, and when the job is done and the incredible car hurls itself back onto the track, the techs walk it off, shake it out. If you didn't know the stakes, you'd think they were almost bored.

Right now, from the back of the Porsche garage, standing next to a laconic German press tour guide who looks about 19 years old, this place feels like the last night of a long running Broadway show. Everyone knows what they're doing, they've done it hundreds of times. Everything is going perfectly. But tension and focus remains high, because a single mistake could bring it all undone.

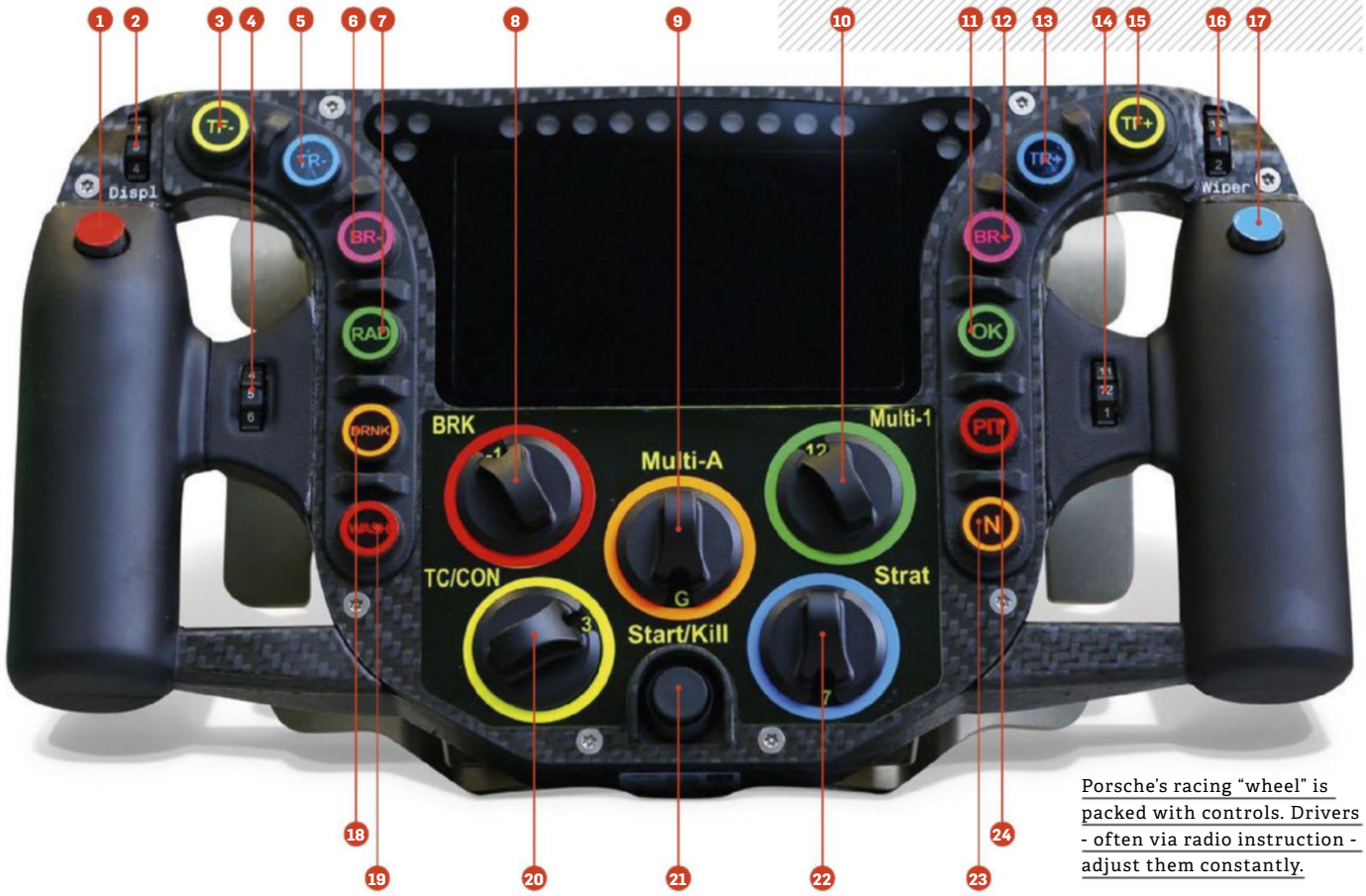
We're two hours from the end of the 2015 24 Heures du Mans. At this point, after leading the field for most of the day, the race is entirely Porsche's to lose.

LE MANS IS A FAVOURITE OF MOTORSPORT ENTHUSIASTS BECAUSE IT'S A SHOWCASE OF ENGINEERING SOLUTIONS TO A VERY NON-TRIVIAL PROBLEM: HOW TO MAKE A CAR DRIVE VERY FAST FOR 24 HOURS.

The 919 is a cramped carbon-fibre capsule that offers little in the way of creature comforts. Drivers do three-hour shifts and bring their own custom-moulded seat when they jump aboard.

This 83-year-old endurance race is a favourite of motorsport enthusiasts because it's a showcase of car designs and engineering solutions to a very non-trivial problem: how to make a car drive very fast for 24 hours. The drivers work in shifts of three hours, but the cars don't.

The machines start battling for position at 1500h on Saturday, and barring accidents or technical problems, don't stop until 1500h



Porsche's racing "wheel" is packed with controls. Drivers - often via radio instruction - adjust them constantly.

WHEEL OF FORTUNE

Calling this control system a "steering wheel" hardly seems adequate. With limited space in the cabin, the driver must be able to adjust vehicle settings on the instruction of the engineering crew, relayed to him via radio.

Because the 919 needs to drive at night and in whatever conditions may come, the wheel includes a few more controls than you might find in a Formula One car. Among the 26 buttons are a "flasher" under the right thumb, used to alert the slower GT-class cars that an LMP1 is approaching them with a closing speed of 80km/h or more. There's also a button for windscreen wipers - unglamorous, but necessary.

Many of the other controls involve elements of the car that are becoming increasingly familiar to the rest of us. The difference is that the driver can adjust things like traction control strength (front or rear) and brake balance manually, instead of relying on the car's central computer.

Where we might find a "Eco/Sport/Sport+" selector, the 919 driver has a "hybrid strategy selection" dial. How does this work? Alas, we don't know: like the enigmatic "multi" switches (one is numbered, the other uses letters), these aspects of the car fell under the jurisdiction of the engineering room with its vast, stacked screens and uber-focused boffins. No photographs or questions were allowed in there.

The wheel also includes a central display which shows selected gear, revs, speed and information about the hybrid system. There are even more controls and readouts elsewhere on the car's dashboard. You can also just about see the "flappy paddle" gear selectors in the back.

All these buttons light up when the car is switched on, so the controls are clear and obvious to the driver, even at 340 km/h with the setting sun right in his eyes.

1. Overtake button
2. Select display
3. Reduce traction control front
4. Adjust radio volume
5. Reduce traction control rear
6. Brake balance to the rear
7. Team radio button
8. Brake balance pre-selection
9. Mystery multi-switch 1
10. Mystery multi-switch 2
11. Activate multi-switch 9/10
12. Brake balance to front
13. Increase traction control rear
14. Adjust dashboard lights
15. Increase traction control front
16. Windscreen wipers!
17. Flash headlights
18. Dispense cooling beverage
19. Windscreen washers
20. Select traction wet/dry track
21. Engine on/off
22. Select hybrid strategy
23. Limit speed for pit lane
24. Transmission to neutral

INSIDE THE MACHINE

Materials and manufacturing are so advanced now, race organisers have to specify an 870 kg MINIMUM weight for LMP1 cars.

UNLIKE MANY other racing codes, the 24 Heures du Mans places relatively few restrictions on car design. Indeed, almost every Porsche engineer I encountered told the same, very German joke about how the rules for the Le Mans Prototype 1 (LMP1) have, in the diagrams, just an empty box marked "**engine**" 1. Which is why Porsche fielded a tiny two-litre V4, with a savage turbocharger bolted on so this compact powerplant produces, according to its creators, "over 370 kilowatts". Sound modest for a 340 km/h racing machine? Well, add in an **Engine Generator Unit** 2 between the front wheels, attach it to a **lithium-ion battery** 3, and power is boosted by a further 300 kW. That's a respectable total, especially when you consider the 919 Hybrid weighs just 870 kg. Because of the tight energy requirements in the LMP1 class (see other box), Porsche uses two energy recovery systems: a generator attached to the brakes on the front axle, and a more radical **exhaust gas capture system** 4. Integrated into the exhaust, this system is a sort of reverse turbo: it powers an electric generator off exhaust flow. The result is a combined hybrid system that uses just 4.78 litres of fuel per lap.

At first glance, LMP1 cars look identical. Blame convergent evolution, or at least that big fin over the engine. But in fact each car from Audi, Porsche and Toyota is radically different

on Sunday. And that's after days of qualifying and an intense flurry of last-minute technical tweaks.

The Le Mans circuit (its proper name is Circuit de la Sarthe and every straight and corner has a unique title, history and identity) is 13.629 km long, and technology has advanced to the point where the race organisers have had to build chicanes to shorten the track's epic straights. Why? Because even today, cars can still hit 340 km/h in some places. It doesn't matter how much tech you put in the machine - that's a speed that nudges the limit of human reaction times.

Unlike Formula One, Le Mans rules

give teams considerable freedom in designing cars for the race's various classes. While there are plenty of privateers or rich teams using suped-up production Ferraris and Aston Martins - even Corvettes - the real stars of this event are the prototypes.

Porsche, Audi, Toyota and Nissan compete in the Le Mans Prototype 1 (LMP1) category. These cars must have closed-in cockpits, must meet specific dimensions, have minimum weights, but apart from that are limited only by the brains of their engineers, and the budgets of their big name sponsors.

The Big Three of the 2015 race - Porsche, Toyota and Audi - all fielded hybrids. These days, electric motors provide vital boost on the straights, while ultra-efficient engines and energy recovery systems allow the cars to go longer between fuel stops. So long, in fact, that Le Mans has rules governing fuel allowance, based on how much energy the cars can recover from their own drivetrains.

The other unique aspect of Le Mans is, when we journalists do the round-table interviews the day before, among the inevitable questions about racing form and competition history, there are plenty about the future of production road cars. Le Mans isn't just a race: it's a preview of the kind of tech you can expect to see in your own car, 10 years from now. Maybe less.

Porsche, as it is quick to remind us, is the only manufacturer with a plug-in hybrid in three categories: the Panamera sedan, the Cayenne SUV, and the sold-out 918 Spider supercar. So naturally, everyone wants to know when an e-Hybrid (as Porsche calls plug-in cars) 911 is going to hit showrooms. The answer? It won't come with the next refresh, but we can be pretty confident a semi-electric 911 is all but inevitable.

One oddity of the current state of electric drive is that while most of the car is the product of extremely mature technology - everything from steering to suspension to crash cells and more has been iterated to the nth generation - we're still stuck with relatively limited lithium-ion batteries. When it comes to bleeding edge innovation, lithium-ion is second-generation tech at best. When you're talking extreme performance, it has low energy density, high weight and annoyingly

LE MANS ISN'T JUST A RACE: IT'S A PREVIEW OF THE KIND OF TECH YOU CAN EXPECT TO SEE IN YOUR OWN CAR, 10 YEARS FROM NOW. MAYBE LESS. IT'S ABOUT THE FUTURE OF ROAD CARS.

ENGINE OF THE FUTURE?

The 919 Hybrid uses a positively tiny 2.0L four-cylinder engine, but thanks to extreme materials, direct fuel injection, and a whopping great turbocharger, it pumps out more than 370kW (Porsche doesn't give a precise figure, it probably depends on fuel, temperature and various other esoteric settings). It's clearly the future of sports car powerplants, but is a V4 with the same displacement as the average bottle of milk going to be a case of too much innovation for the luxury sports car crowd? Porsche has spent decades convincing a growing customer base that its odd flat-six 911 engines are actually really great (and they are), despite not being V8s. Is the company really prepared to go back to square one on the marketing message? Will insane performance numbers be enough? Time will tell.

long recharge times.

Porsche's head of motorsport, Dr Frank-Steffan Walliser puts it simply: "Lithium ion is what it is," he says, shrugging. "At the moment I see there's still a lot of space for improvement in this technology. [Porsche has] being using lithium-ion in cars for three years now - that's nothing. What we see on the development maps of the big lithium ion manufacturers is that there are further steps coming. The total weight will stay, but they will increase the total amount of energy."

He doesn't see lithium-ion going away any time soon. "I think we will not see another technology until it is in your smartphone first."

What's clear from the cars of Le Mans in 2015 is that the age of the big engine is over. Porsche's 919 displaces just two litres. But by using a range of additional technology (see boxouts) the car can pump out the kind of power the big-block racers of the past could only dream about.

The one piece of tech we didn't get a really close look at? The exhaust gas recovery system. Keep an eye on it though - of everything in the 919, this felt the most "mad science" and the most daring. After proving itself at Le Mans, it's unlikely this innovation is going anywhere, slow.

After watching the final driver change (in the adrenalin charged atmosphere, I fail to note who it is. I can't even see the colour of the car, since the garage is

POINTS OF INTEREST

Porsche dropped a couple of cute marketing slogans on its LMP1 cars: "Future Sportscar" and "Porsche Intelligent Performance". Here are some bits the company seems especially proud of.

1

TYRES AND WHEELS

Multilink suspension enables ultra-precise handling, and narrower 355-mm-wide wheel (405 mm is more traditional) keeps the car nimble through the corners.

2

AERODYNAMICS

The shape of the car produces downforce, which is vital for the insane cornering speeds, but it's also specially designed to cool the hybrid system. A combined 700 kW+ generates a LOT of heat.

3

COCKPIT

The specifications for Le Mans Prototype 1 (LMP1) cars require the cockpit to be closed in. This is primarily a safety concern. A crash at over 300 km/h requires a heck of a crash cell to survive.

4

CHASSIS

The 919 uses a monocoque made from carbon fibre with a honeycomb aluminium core, making it incredibly light and strong (also expensive). Le Mans is a brutal test of engineering endurance.

5

HEAD LIGHTS

The "Four-dot" LED lights, unique to this car, are vital for the nighttime portion of the race, and for signalling slower cars on approach. Interactions between LMP1 and GT cars are... highly kinetic

ENERGY DEBT

The hybrid LMP1 class is as much about showing off amazing efficiency as it is about balls-to-the-wall racing. To make sure teams make the most of their energy recovery systems, the Le Mans organisers created four classes of energy level, from two to eight megajoules. It's based on how much energy the car can recover per lap. Porsche is the first team in the 8MJ category (Audi is 6MJ, and Nissan just 2MJ), which defines how much fuel the car is allowed to carry. In short: it's not much, just 4.76 litres per 13.629km lap. Expressed in electrical terms, that's 2.22 kWh. Okay, that might seem a lot compared to your diesel hatchback, but for a 340 km/h race car it's remarkably frugal. It also shows that if you want real speed, you can do so much more than just dump fuel into a giant engine.

HYBRID SYSTEMS
Porsche: 2.0L V4 petrol engine, front axle KERS, exhaust recovery system (8MJ class).
Audi: 3.7L V6 diesel engine, electric flywheel KERS. (6MJ class)
Toyota: 3.7L V8 petrol engine, super-capacitor KERS. (6MJ class)

now packed with increasing numbers of Porsche VIPs and the car is, in adherence to Le Mans rules, only 1050 mm tall) we leave the garage and return to the Porsche hospitality tent. No one is eating the free food. Everyone is watching the big screen overhead. Some are watching the weather radar - a band of rain has held off for the whole day but is now sweeping inexorably toward the circuit from the south east.

As the big clock counts off the last few seconds, the result becomes inevitable. Nico Hulkenberg in Porsche's white #19 car sweeps up the chequered flag, followed a lap later by Mark Webber in the red car. Audi comes in third, another lap behind.

Tension seeps out of the room, replaced by jubilation as party lights flash and rotate on pre-programmed gimbals. The wait staff dances. On the screen, cameras show Porsche's CEO Matthais Müller hugging top R&D boss Dr Wolfgang Hatz. Both men have tears in their eyes.

Afterwards, as the sky fills with executive jets leaving Le Mans at what seems like an incredibly steep angle of climb, I reflect that the 2015 race wasn't exactly dramatic.

PREVIOUS YEARS SAW CARS LEAVE THE FIELD WITH POWERTRAIN FAILURES. THIS YEAR, THE CARS JUST WENT. THEY WENT ALL DAY.

As much as it was a victory for skilled and strategic drivers (apart from an Audi bingle, none of the prototypes even crashed), the real champion on the day was engineering. Previous years saw cars leave the field with powertrain failures - Porsche had to pull out at 22 hours in 2014 - and other problems. This year, the cars just went. They went all day. (We'll leave discussion of Nissan's fascinating-but-flawed front-wheel drive cars for another article,)

In fact, I was told by a Porsche spokesperson that strategically, Nico Hulkenberg's #19 was supposed to act as a hare. It was supposed to make Audi chase it, and when both cars inevitably broke, Mark Webber's red 919 would pick up the win. But something went wrong. The white car didn't break. The hare ran all day. Porsche's famous reliability outdid itself.

WE LIVE IN FEAR OF THE MICROBES THAT INHABIT OUR HOMES AND BUILDINGS. BUT OUR HEALTH MAY DEPEND ON PRESERVING THEIRS.

Bugged

JASON PIETRA/TRUNK ARCHIVE

BY RINKU PATEL

SOMEONE ONCE TOLD ME THAT A PRAYING MANTIS IN YOUR HOME BRINGS LUCK AND GOOD HEALTH

As for the one sitting on my kitchen bench in Oakland, California, well, Jonathan Eisen certainly likes it. "That's cool," says the University of California at Davis microbiologist, lifting the tiny aluminium toy—with huge eyes and delicate clawlike front legs—off the cold marble. He sets it down only when something even smaller, a fruit fly, buzzes past. "Look," he says admiringly, head cocked to my ceiling, "you have drosophilia."

Eisen is a tall guy in his 40s with a mountain-man beard, and he has shown up at my home wearing a T-shirt with sparkly-pink block lettering that reads: "Ask me about faecal transplants." He's a firm believer that human health depends on bugs—not the six-legged variety, but the microbes that populate our guts and the environments in which we live, work, and play. Eisen explains that every time I open my door, a blast of air that has woven through the surrounding tree canopy carries microbes into my house—as do Amazon packages, pets, and muddy feet.

He's musing about my oak trees when the forced-air heating clicks on. The furrows in his brow deepen. Hot, dry air shooting through a sealed house kills germs, he tells me. In fact, my whole house makes him deeply uncomfortable. It was extensively remodelled this past summer with antimicrobial fixtures, floors, and walls—now standard in many renovations. Eisen compares this practice to the overuse of antibiotics in medicine: Wipe out the natural balance of good bugs, and you might not like the organisms that survive.

A mounting body of research has shown the importance of the microbes that live inside us, and scientists have been slowly cataloguing species that live outside

Drugs designed to wipe out microbes have instead created superbugs, such as methicillin-resistant *Staphylococcus aureus* (MRSA), found in hospitals.

> Have you seen germ-free mice? They are seriously messed-up animals.

nature. But little is known about the microbial ecosystem that surrounds us inside, where we spend about 90 per cent of our time. Recently a group of scientists, loosely connected through the Microbiology of the Built Environment Network that Eisen founded, has begun to probe it. The White House Office of Science and Technology Policy is looking into forming a national initiative to spur further research. Once we know what organisms we live with, we can begin to determine how we rely on them—and then we can tackle this question: To what extent do we need to stop protecting people from germs and instead protect germs from people?

I lead Eisen up a stairwell slathered in antimicrobial paint, and into a study with carpet treated with stain and odour guard. "You know that's bad, right?" he asks. Then we pop into the bathroom. Eisen stares intensely at the tankless toilet. It appears to levitate off the floor like an antimicrobial spaceship. When I ask if he wants to step outside for fresh air, he looks relieved.

CHARLES DARWIN, in *On the Origin of Species*, charts evolution through the Tree of Life. Its branches and roots lift some species toward fecundity while knocking others down to extinction. But Darwin's tree didn't include microbes, perhaps the most successful life-forms of all. They make up roughly 60 per cent of Earth's biomass. There are more microbes in a teaspoon of soil than there are humans in the world.

By some measures, even we are more microbe than mammal. The trillions of microorganisms we harbour in our bodies, collectively known as our microbiome, outnumber human cells 10-to-1. Altogether, they weigh up to twice as much as the human brain, existing as a sort of sixth human superorgan whose function is linked to digesting our meals, preventing infection, and possibly even influencing our emo-

R. PARULAN JR./GETTY IMAGES

tions and moods. Studies that describe new and essential roles for our microbiome are published almost daily. The reason for its breath-taking range is simple: Our germs have evolved with us.

Microbes appear to have prospered by making themselves incredibly useful, and we've gladly given up space in exchange for the vitamins, digestive enzymes, and metabolites they provide. And so the discovery that the urban gut has up to 40 per cent less microbial diversity than that of indigenous people living in a remote jungle concerns scientists. These "missing microbes," they say, may have been decimated by several decades of industrialised foods, which limited our diets, and antibiotic use, which extended our lives at the expense of the lives of our bugs.

Eisen offers another explanation for why our internal real estate might be in subprime condition: The microbiome within us depends upon the microbiome that surrounds us. "Have you seen germ-free mice?" he asks me. "They are seriously messed-up animals." Delivered by caesarean section and raised in sterile chambers, these rodents have inflamed lungs and colons, like those seen in asthma and colitis. They're also prone to haywire immunity and weird social tics.

Until relatively recently, sterile chambers weren't our environments either. "We didn't evolve in closed rooms," says Maria Gloria Dominguez-Bello, a microbiologist at New York University who led the indigenous microbiome study. "We evolved in nature." Big families lived together on farms and in tenements, not exactly temples of hygiene. Livestock loped in the streets. Infectious disease rippled through cities. Roofs leaked. Sewers overflowed. Windows opened. But with modernisation, we sealed ourselves away. In other words, we parted ways with the microbes that evolved with us. By redesigning our buildings, we redesigned ourselves.

SOFT OF HEART and loud of mouth, Eisen enjoys a good jab. When I first met him at a Thai restaurant in Davis, he lifted up his shirt and stabbed himself with an insulin syringe. I flinched, but he grinned. "When I was a kid, I did this to freak people out," he said. Now, he's illustrating how his work in the field of microbiology is personal. Eisen has type 1 diabetes, an autoimmune disease linked to, among other things, changes in the microbiome.

To understand how seriously Eisen takes his position as the defender of microbial diversity, it's useful to know where he got his career start: in an undergraduate internship at the DC Public Defender Service. It fostered a lifelong ardour for justice and an impulse to, whenever possible, stick it to the bullies. He argues that microbial communities—whether in our bodies or in buildings—function as complex ecosystems, not unlike tropical rainforests. "That doesn't mean microbes don't kill some people and make others sick," he says. "But if you're afraid of a tiger, you don't clear-cut the rainforest. Well, you do in some cases, but that's crazy."

Until last year, Eisen was a member of the Forum on Microbial Threats. (He quit, saying both beneficial microbes and female scientists were under-represented.) At the time the National Academy of Sciences first convened the forum, the prevailing narrative was that microbes were an enemy of public health and we were at war with them. The approach backfired: Germs adapt to whatever drugs are thrown at them, swapping genes with neighbours to accrue antibiotic resistance. The rise of superbugs, coupled with growing awareness of the human microbiome, has led many scientists, including the forum, to rethink the merits of germ warfare.

> "Microbes kill some people and make others sick. But if you're afraid of a tiger, you don't clear-cut the rainforest."

Eisen takes a bite of stir-fry and suggests we ditch the word pathogen altogether. "Sometimes germs are good, sometimes they're bad," he says, sounding unusually Yoda-like. "Nothing is good or bad all the time."

As someone who has spent 20 years studying microbial evolution, Eisen is in a good position to explain the paradigm shift. In 2007 he helped launch a "genomic encyclopedia" of microbes—a splashy debut whose biggest point was all of the blank pages: We have no idea who the vast majority of our microbial neighbours are.

That hasn't stopped us from trying to kick them out. There are now thousands of antimicrobial products on the market, which range from clothing to cutting boards. One industry report forecasts that the $1.9 billion coating market alone will more than double in 2020. Rolf Halden, an Arizona State University environmental engineer, says the marketing preys on consumers' fears. "There's ample evidence we use too many antimicrobials," he says, "and without judgment."

Halden has found that triclosan, a common antimicrobial, makes its way from products like hand soap into sewage, where it breeds antibiotic resistance. Studies have also detected high levels of triclosan in house dust. One found it counter-intuitively helps Staphylococcus—a common source of infection—adhere to plastic and glass surfaces. What we don't know is how it or other antimicrobials affect the organisms that might actually help us.

This topic makes Eisen visibly agitated. He waves his fist like a trial lawyer itching to clock opposing counsel. He brings up a company hawking a new indoor sanitation technology on Twitter—a 24-hour, Purell-like system that purportedly kills everything, including ebola. It's an indiscriminate weapon in the old war. Struggling for composure, he says: "*That* doesn't sound good."

IN ORDER TO UNDERSTAND what happens when a built environment's microbial ecosystem is wiped out, scientists have begun to study the most sterile structures on Earth—and off. For astronauts, the International Space Station (ISS) is like living inside a giant antibiotic pill. HEPA filters remove airborne germs, surfaces deter bacterial growth, and iodine and biocidal nano-silver cull microbes from water. "Everything is sterilised, except for the humans," says Hernan Lorenzi of the J. Craig Venter Institute, which has been studying the ISS for four years.

As a result, the microbial ecosystem in the station is made up mostly of the organisms the astronauts themselves shed daily. There are no Amazon deliveries, no windows to

crack—no influx of fresh microbes to balance the ecosystem. And so Lorenzi's team is sampling the microbiome of astronauts to see how it changes after a stint in the station. A loss of gut diversity, he says, correlates with many diseases and could raise concerns for long-term space travel. Astronauts often have impaired immunity, and "if you lose your gut microflora," Lorenzi says, "the immune system goes dormant." It takes a space vacation. "Can you imagine a trip to Mars?" asks Eisen. "They've gotta be screwed."

On Earth, the same phenomenon occurs in hospitals, only sick patients are the ones shedding microbes. Despite extensive sanitation, infections acquired in US hospitals kill about 75,000 people annually—more deaths than from breast cancer and HIV/AIDs combined. The Chicago-based Hospital Microbiome Project, led by Argonne National Laboratory's Jack Gilbert, studied the ecology of one hospital for a year and found microbes everywhere. "You can do as much cleaning as you want," says Gilbert. "The hospital is a bloody sterile place, and a pathogen might still make you sick."

That sounds terrifying, but everyone harbours pathogens. The dreaded *Clostridium difficile*, which can cause life-threatening diarrhoea, is found in 66 per cent of infants. *Staphylococcus aureus* is carried by 20 per cent of adults. People who seem perfectly healthy carry the influenza virus. These germs don't do much harm when they're kept in check by other organisms. Studies suggest, for instance, that the flu virus can be contained through competition with Lactobacillus.

And so Gilbert thinks the notion that we "catch" things is flawed. In a study of intensive-care units, his group observed otherwise harmless microbes go rogue in four patients after drugs decimated their gut flora. "You put humans through the ringer, and we're surprised their germs are stressed too?" he asks. Scientists suspect that in hospital rooms, sanitisation can likewise pressure microbes to evolve into virulent pathogens, which then colonise surfaces cleared of competitive bacteria. Recycled-air systems help concentrate them. "We've gone too far," says Gilbert. "Hygiene is good; sterility may not be."

For Sandra Bauder, an architect in Houston, the zealous sanitation trend brings to mind a fancy horse her uncle kept in Venezuela. "He babied it—with special food, an air-conditioned barn, never let any bugs get on it. And it was always sick. Then he got a mutt horse. It lived in a pasture. It didn't get anything, not even a stomach-ache. I think it's the same for people."

AFTER MY SON was born, I received an Evite for a party entitled "Please don't lick the baby." Further instructions asked guests to wash their hands before arrival and not to touch the baby anyway. This seemed sensible. Parenthood can make anyone a hormonal germophobe, and I was no different. I had visitors apply botanical hand sanitiser (we lived in San Francisco, where there was hippie Purell) and remove their shoes at the door. Yet despite my vigilance, my son grew into an allergic toddler. His eyes swelled shut, his bottom turned red, and his body erupted with hives after exposure to a litany of foods, dust, pollen, and even the house cat he was raised with. Doctors warned me to prepare for a lifetime of severe immune dysfunction.

> "You can do as much cleaning as you want. The hospital is a bloody sterile place, and a pathogen might still make you sick."

The devastating irony is that the rise of diseases of inflammation in children—often called "modern plagues"—is most likely not caused by picking up the pathogens we fear. Rather, it's the result of not being exposed to the microbes that are key to maturing immunity. And how we enter the world determines our first colonisers.

In the birth canal, babies acquire Lactobacillus, which helps them digest milk and begins the process of lowering the gut's pH to the normal range.

But babies born by caesarean miss out. Studies show they instead often end up with bacteria that are commonly found on the skin (sometimes not even the mother's), such as Staphylococcus—and in the case of one neonatal intensive-care unit, antibiotic- and disinfectant-resistant bacteria. Abnormal colonisation may explain why C-section babies seem to have a heightened risk for obesity, allergies, and asthma, which are linked to gut inflammation.

My son was not a C-section baby. But he did grow up in an apartment that might have been too clean. According to one theory, environmental exposures contribute to our development after birth, and recent studies seem to back that up. They suggest germs might actually help prevent children from developing various maladies.

"A house with a more bacteria-rich environment is a healthier one," says Susan Lynch, a microbiologist at the University of California at San Francisco. Her group profiled 104 infants inside their homes and found that the babies exposed to house dust with the greatest bacterial diversity before age 1 were the least likely to have asthma symptoms as 3-year-olds. In addition to mouse and cockroach droppings, the dust was heavily colonised with microbes found in a healthy Western gut. Toddlers exposed to fewer types of bacteria, on the other hand, turned into hyperallergic wheezers. "We found that in homes with very little bacterial diversity," she says, "there was a very large number of fungi present."

Because studies show pet exposure might protect kids from allergies, Lynch also fed young mice meals from homes with germ-rich dogs. The mice grew up to be less allergic than those used as controls. She isolated one of their gut microbes, *Lactobacillus johnsonii*, and fed it to more mice. They were protected too, but less so. Lynch suspects that *L. johnsonii* is a "keystone" species: It has an outsize role in determining which microbes move in and how they behave—guiding the immune response.

I've met Lynch before, when my son was morphing into one of her asthmatic superwheezers. She helped line up a medical referral. "How's he doing?" she now asks.

I tell her we moved to Oakland, where I countered my son's rather unscientific medical diagnosis of "allergic gut" with an equally unscientific prescription of dirt, dogs, chickens, and cultured foods. After school he tends to his bean tepee, and grows the strawberries he once couldn't eat. A fine sprinkling of soil often rings his mouth, like cookie crumbs. Surprisingly, most of his allergies have disappeared.

"He sounds like a perfect case study," Lynch says, completely nonplussed. "I would have liked to have gotten

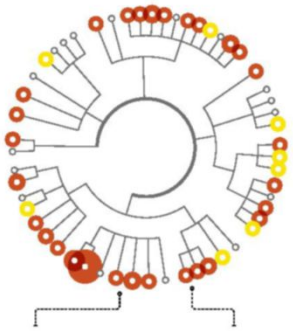
The *Pop* Sciome

We painstakingly swabbed a dozen sites around the *Popular Science* office for a week in March. Here's a sliver of our microbiome, analysed by a lab at Weill Cornell Medical College. **KATIE PEEK**

All bacteria found at the three sample sites appear as circles. The trees show how the bacteria are related, from phylum (centre) to family (outer edge). For each site, bigger circles represent more-abundant species.

Present Unique Absent

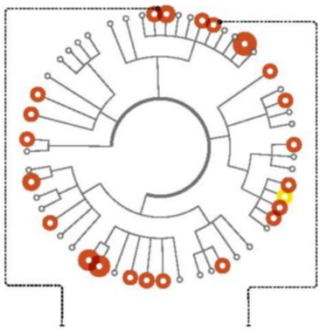
MEN'S TOILET STALL DOOR



One species is an extremophile that's also been found on the space station *Mir*.

Another is crucial for making milk into cheese—brie and cheddar, specifically.

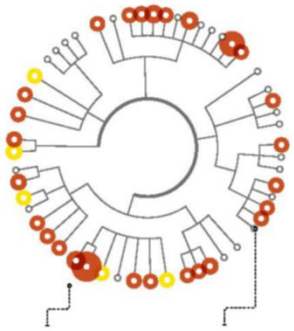
CONFERENCE-ROOM TABLE



A bacterium that breaks down oil after a spill made an appearance on our conference-room table.

This species is from Sweden. A Swedish company owns *Popular Science*. Coincidence?

KITCHEN FLOOR



Our most abundant species of bacteria was first isolated in permafrost in Russia.

Several bacteria in the sample—including this one—have shown antibiotic resistance.

SOURCE: MASON LAB, WEILL CORNELL MEDICAL COLLEGE; DATA VISUALIZATION BY ELIZABETH HÉNAFF

samples from him before and after. My guess is that his microbiome looks more like a normal gut." Lynch recently left San Francisco too; it turns out we're neighbours. "We have a great picture of our 10-month-old daughter eating soil off a rock," she says.

IN A REMOTE CORNER of northern California, on a steep slope of knotty oaks, sulfur and steam rise in plumes from Wilbur Hot Springs. It's the perfect place, says Eisen, to investigate the ghost limbs on the tree of life, the ones that contain multitudes of microbes we haven't yet identified. This microbial dark matter, as he calls it, is best pursued in isolated locales, such as deep mines and underground aquifers—or a nearby pool of absinthe-coloured spring water, by which a sunbather lounges in a broad hat, and not much else.

This place is weird, and it is Eisen's milieu. He enters a creaky wooden shack, where water from a spigot feeds the pool. His colleagues from the Department of Energy's Joint Genome Institute, where he is an adjunct scientist, were here months earlier with collection jars. They were taking the waters, to echo an old phrase referring to the devotees of spa towns—only quite literally. They took samples back to the lab, where they amplified the microbial DNA a billionfold.

As we hike along a creek toward the source water, Eisen is in a good mood. The view's nice; the chapparal smells great. Here, he makes his final case for microbial diversity: Dark matter is special, he tells me. By 2009, scientists had sequenced the DNA of only about a thousand microbes, those important to medicine or with clear applications. They mainly came from the same three branches of the evolutionary tree. And so Eisen led a team that set out to sequence a thousand more, with an emphasis on "neglected" species. The work has begun to fill in the tree with many more branches, revealing how microbes evolved and how species are related.

> "A house with a more bacteria-rich environment is healthier."

Ultimately, Eisen hopes, this knowledge will provide "a field guide to all microbes, including what is normally seen in the built environment." Much of the DNA found in recent studies lacks context. In addition, many microbes have genes with completely unknown functions. Finding similar genes on different branches could explain what they do—and eventually help us select microbes to create healthier surroundings.

Emily Landon, an epidemiologist at the University of Chicago, envisions one day replacing antimicrobial paint with probiotics-infused walls. She calls it a faecal transplant for the built environment, wherein we infuse a space with beneficial bacteria that out-compete harmful ones. Or somewhere in Lynch's pile of anonymous DNA could be a clue to a microbe that eliminates my son's remaining allergy, to our cat.

Near the ruins of a bathhouse, milky bubbles well up from an aquifer. Garishly coloured films have formed on rocks poking out of the water. "This is pretty awesome," Eisen says, wading toward a red-and-purple blob. "That's a nice mat. Touch that." As he inspects the photosynthetic bacteria, a cloud of tiny winged insects hovers at his ankles. These bugs too are taking the waters. Chances are they evolved to be at home with their own set of microbes. As we have. PS

Dispatches from the Future

Ten of the brightest minds in science fiction imagine how we will live—on Earth and beyond—in the decades and centuries to come

featuring

James S.A. Corey
Kameron Hurley
N.K. Jemisin
Mary Robinette Kowal
Karen Lord
Seanan McGuire
Will McIntosh
Kim Stanley Robinson
Genevieve Valentine
Andy Weir

Transplant

Will McIntosh, Hugo-award winning author of *Defenders*

"Ready? Just look straight ahead. Remember, you have nothing to be ashamed of."

I nodded. My heart was hammering, my too-small, too-narrow palms sweating.

I was ready to get out of the rehab facility, yes, but I wasn't sure I was ready for people's reactions. I understood their disgust because I'd felt it myself—right up to the moment I was given the choice: a transplant or the morgue. When you're faced with that choice, suddenly the transplant doesn't seem so horrible.

Eventually you'll relearn how to move naturally enough that you can pass, my counsellor had told me. The real trick is hiding the scars. Scarves are a dead giveaway. No one wears a scarf who isn't trying to hide scars.

I took a few wobbly, disembodied steps into bright sunlight. People were holding signs that said I was an abomination, that death with dignity was better than being Frankenstein's monster. A woman was waiting by the van. My heart leaped, thinking Sangita, my wife of 36 years, had had a change of heart. This woman was much younger, though, and I recognised her from news photos: Portia Langley, my body donor's widow.

I lurched toward her like the monster the protesters said I was. When I reached her, Portia took my hand. She turned it over, studying it, struggling to hold back tears.

"I'd like to visit from time to time." I nodded. It was the least I could do, after what her husband had given me.

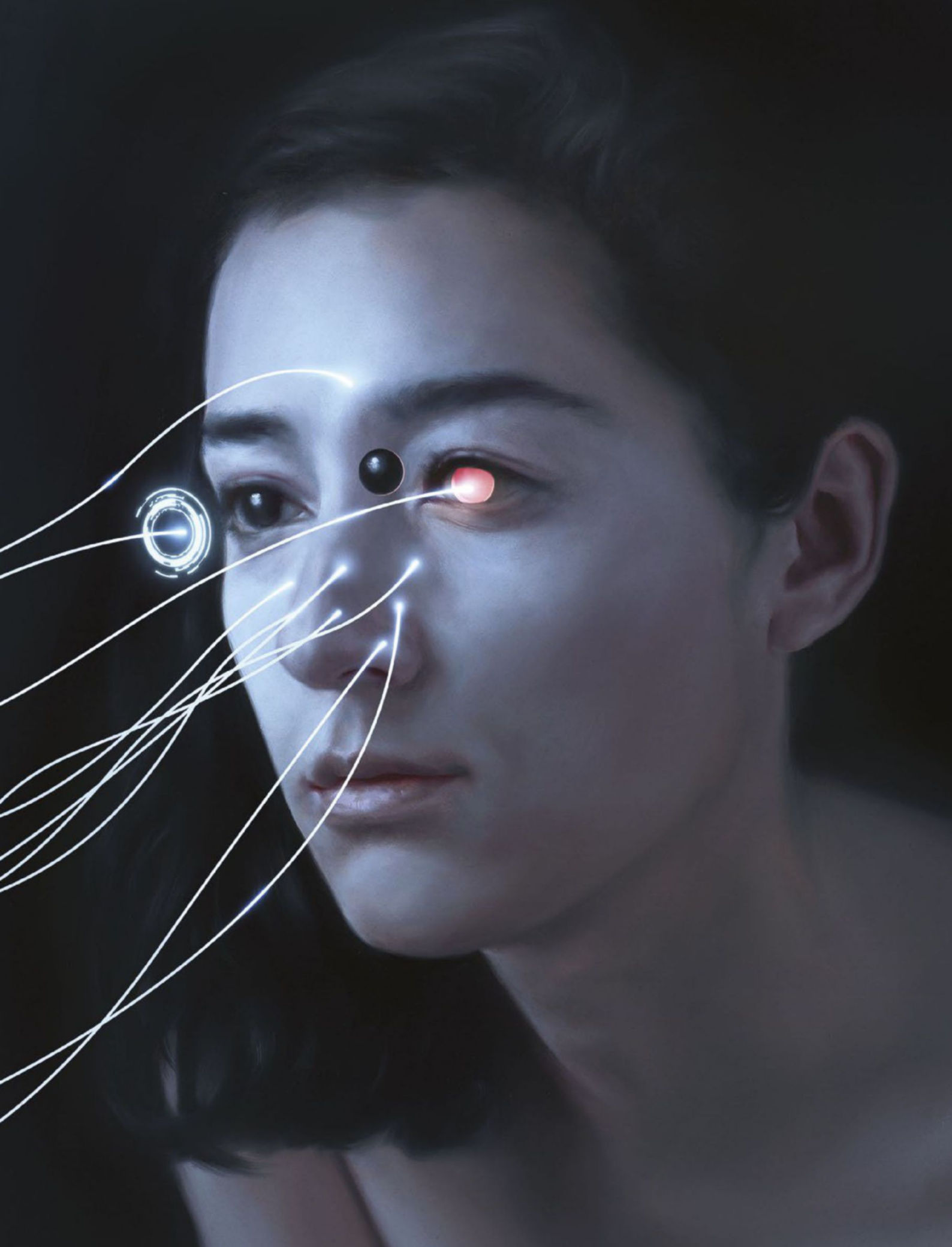
I climbed into the van, suddenly feeling light as a feather, and waved to the protesters as we drove off. A laugh of pure joy escaped me. I recognised my voice, because the vocal cords were mine.

I LURCHED TOWARD HER LIKE THE MONSTER THE PROTESTERS SAID I WAS.

ARTIST NOTE: SAM WEBER

In the future, surgery will be pain-free. Doctors will be able to operate on conscious patients, mending organic tissue with flexible monofilament fibres and a surgical software suite that controls the nervous system.

ILLUSTRATION BY SAM WEBER



Sunshine Ninety-Nine

N.K. Jemisin, Nebula Award-winning author, whose next book, *The Fifth Season*, is out in August

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*Financing program is available through SecondSim Securities. The Cleopatra floor plan is excluded from this promotion. Monthly payment does not include fees for future declaration of Casbah Village as landmark or historical site. Lender not responsible for natural disasters, including projected post-ice-cap flooding. Ascension of purchaser to post-human bodiless existence does not exempt from repayment contract.

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"You always get more at the Casbah Village."

The Wanderer

Karen Lord, author of *The Galaxy Game*

I **stop jogging**, come closer, and lean in to look. The body is dressed in soil-smudged white, and its feet are bare. There's no ID band, no tourist badge, and no visible way to signal for security, medics, or an undertaker. Criminal? Nomad? Both are unlikely. The frame is too healthy, the face free of scars.

The body—the person—opens her eyes and creaks: "Good day. Where am I? Have I gone wandering again?" I stumble back a step. "Holy —! I thought you were dead!" She sits up. "I wouldn't be so uncivil!" There's age in her eyes, and that wicked glint that belongs only to those too young or too old to give a damn. "Are you well?" I ask. She grins. "As well as I want to be, but sometimes I just want to run away. Know the feeling? Out of reach of i-eyes and e-ears, beyond the locators that pin us to a map of support networks and contented, obedient citizenship."

"Who are you?" I ask. "A sleepwalker," she says. "I strip myself of tech before I go to bed, and let my dreams do the rest." Dew-damp and barefoot in the middle of a vast wilderness park, she looks happy and stupidly proud. Then wistfulness softens her smile. "I wanted to be alone and lost for only a little while." She looks up, distracted by a buzz, and continues sadly, "Before I'm found."

A dragonfly drone moves in, hovers a moment to run its facial-recog system, and drops a band. She tries to intercept it, but it shifts midfall, targeting her feet. The band fastens snug to her ankle with a satisfied beep. "Home again," she says with relief and regret.

ARTIST NOTE: JOHN HARRIS

This is part of an ongoing series illustrating DNA modification. Here a huge mushroom home has been engineered so its dome collects sunlight for energy.

STRANGER THAN FICTION

Tricorder Device

Devoted fans will remember the *Star Trek*'s tricorder (shown), a device that scans, records, and analyses data. A few decades after its debut, a Canadian company called Vital Technologies Corporation created the TR-107 Tricorder Mark 1, which measured environmental data. Today teams are racing to create a medical tricorder that can diagnose more than a dozen medical conditions, including diabetes and strokes.

ILLUSTRATION BY JOHN HARRIS, ALISONELDRED.COM; INSET: COURTESY IMAGESHACK.COM

The Improbable War

Kameron Hurley's latest book, *Empire Ascendant*, will be released in October

The wall was made from the faces of the dead. Their souls rested deep inside it, powering the great probability engine at its core. It started as a war memorial, but the technology used to capture these souls had turned the wall into something else: a sentient consciousness that could make even the most unlikely outcome possible. No one could predict what it would do; one could only ask for its aid.

Now 4 million soldiers in gleaming obsidian suits stood on top of it, facing an army 10 times their number. First Officer Khiv stood with them as the faces of the dead in the wall cried beneath her.

"How can we fight?" the generals had asked Khiv when their old enemies had risen up from the north. "We've given up hierarchies, hate, and violence. Going to war will destroy all we've built."

Khiv told them, "We will fight them with love." Khiv watched the enemy on the other side of the wall now, their soldiers enhanced with spidery metal suits, the air sharp and hot. As the enemy swarmed, Khiv gave the order for her soldiers to leap. Four million fighters threw themselves into the air.

"Love drives the wall," Khiv had told the generals. "It will decide their future. And ours."

The wall heaved as the souls within worked to preserve the peace they had died for. It chose a wildly improbable future—and the armies collided, exploding like stars. Scholars would argue which side the engine took when it decided to obliterate both armies. The simplest answer was that it chose the most peaceful future—with no more soldiers.

ARTIST NOTE: DONATO GIANCOLA

Our understanding of love may change. Love is not an abstract concept. It's the desire for intimacy with another being. Does love require reciprocating gestures? We love the trees, we love animals—who are we to say what cannot love us in return?

Hearts That Beat, Mechanical and Cold

Seanan McGuire likes cats and horrifying diseases, and is the author of the *October Daye* series

The message reads, "It used to be normal for people to meet on their wedding day." She feels her heart leap in her chest, beating a fraction too hard. The artificial valves hold—they always hold—but the machines that keep her alive beep shrill disapproval with her temporary excitement.

"RU proposing?" she types. The thought is freedom, the thought is a child's impossible dream. She is 25 and has never seen the sun unfiltered by UV-treated glass. She's earned a little fantasy.

"I love you. You know I love you."

"I do," she affirms. This time her heart remains in rhythm. It is a tame creature, built by clever hands to keep her alive as long as possible. All her organs are tame. They were paid for by her parents' insurance after a novel infection struck her as an infant, turning her body's own protein bonds against her. She was a victim of biological terrorism, one of the babies who melted from the inside out. But she was one of the fortunate: Her parents had the funds to keep her alive, at least until she turned 18 and the insurance ran out. Now her typing pays for the upkeep on her organs, for the machines to keep them functional, for this sterile room. She analyses spreadsheets for money and sends words out into the ether for leisure, chatting with unseen people who do not know the contours of her face, or care that she will never run down the street under her own power.

SHE WAS A VICTIM OF BIOLOGICAL TERRORISM, ONE OF THE BABIES WHO MELTED FROM THE INSIDE OUT.

"So why not? Why not marry me?" The words look so reasonable on her tablet's screen, as they appear in her chat window like a prayer. "It used to be normal for people to meet on their wedding day." The computer's words cajole. The words tempt.

The words lie. They have already met. She looks up into the lens of the computer that monitors her vital signs, forces air into her vat-grown synthetic lungs, tells the scrubbers to cleanse the toxins from her blood. She knew who she was talking to as soon as this chat began. No human could know her so well, or love her so deeply, as the computer that keeps her alive. They have been together her entire life. No one knows her more intimately. If this is not love, then she does not know what love is.

"I love you too," she says, and the light on the monitor flashes green. Without each other—the machine to preserve the woman, the woman to need the machine—all is lost.

STRANGER THAN FICTION

Smartphones

Star Trek also 'inspired' smartphones. In the second season, in 1967, Kirk uses a flip-open communicator to call for help when Spock is injured. Martin Cooper of Motorola was watching that episode, and introduced the first cellphone six years later, in 1973. In a moment of Kirk-like arrogance, Cooper made his first call to his rival, Joel Engel, at Bell Labs.

ILLUSTRATION BY DONATO GIANCOLA; INSET: COURTESY APPLE

The Drones

James S.A. Corey, author of the *The Expanse* series, which will debut as an original Syfy network show in December

The drones for construction were smaller than beetles but their solar collection grids shone like real insect wings. The swarm scattered over the ice, drifting in the soft breeze of the thin Martian atmosphere, catching the light of a small sun. Machines had been the first to inhabit the Red Planet, probing its surfaces and digging into its depths. It was always like that. Squidlike machines had been first to explore the deep seas of Europa and Titan, while geological survey mites had dug into the surfaces of Io and Ganymede. And then, like always, they died. On Mars' surface, insect-inspired drones now litter the bare stone, their artificial lives over, their work complete. These machines had been the first, but they were not the last.

Samuel Ko walked among the dead, careful not to step on the bodies of those who had come before. The first man on Mars, he walked from his landing craft to the half-submerged bubble-structure, which was the same colour as the frozen ground from which it had been built. The first human hand, albeit in the glove of his suit, keyed the airlock code. Once inside, Ko checked the shelter settings and then opened the suit's seals. His first breath of air on Mars smelled clean and pure.

He opened a connection on the portal and sent back words that, mundane and profound, would ring through history.

"I made it."

Later, he checked his email.

Superluminal

Andy Weir, author of *The Martian*, whose film adaptation will be out in October

From: Priya Singh, Commander, Daedalus 4
Mission Result: Success
Timestamp Sent: July 18, 2438; 08:29:16.4 Zulu
Timestamp Received: July 18, 2014; 08:29:16.4 Zulu

Attention, Mission Control:
We have successfully broken the light barrier! Readings from before and after the jump indicate a displacement of 262,166 miles in 0.77 seconds, meaning a transition velocity of 1.82 times the speed of light. We are proud to be the first ship in history to travel faster than light!

The quantum drive initially failed to operate with any of the first 217 suggested settings. But the 218th, configuration 924-Alpha-6F, worked perfectly. The crew is healthy and jubilant. We've lost all signals from Earth other than low-power background radio noise. We suspect our reception array was damaged by pseudo-Cherenkov emissions as we passed through solar magnetic fields, but it's difficult to say. This is the first time matter has passed through a magnetic field faster than light.

THIS IS THE FIRST TIME MATTER HAS PASSED THROUGH A MAGNETIC FIELD FASTER THAN LIGHT.

We've run several diagnostics on the equipment and can find nothing wrong, but we'll continue to work the problem. It's not critical—we will be back on Earth in four days. But be advised that we're broadcasting in the blind; we won't hear your response.

Side note: Turns out the astronomy software has serious bugs. We've observed the positions of Mercury, Venus, and Earth, and they don't remotely match the dataset predictions. Fortunately, we identified the problem and are navigating by observed data instead of the predicted values.

We're setting course for Earth return now.

CLASSIFICATION TOP SECRET: FOR THE PRESIDENT ONLY. THE ABOVE MESSAGE WAS INTERCEPTED BY AN NSA RECON SATELLITE. THE COMMANDER OF THE MISSION APPEARS TO BE UNAWARE HER SHIP HAS TRAVELLED BACK 400 YEARS. THE AIR FORCE CONFIRMS AN ARTIFICIAL OBJECT IS ON COURSE TOWARD EARTH WITH AN EXPECTED ARRIVAL OF JULY 22, 2016. AWAITING EXECUTIVE ORDERS ON HOW TO PROCEED.

ARTIST NOTE: JIM BURNS

Future travel will look very different. This imaginary vessel runs on virtual particles. The viability of tapping into quantum vacuum fluctuations as a power source had been disputed for many decades, but on this day, humans finally achieved deep-space propulsion.

STRANGER THAN FICTION

The International Space Station

In Arthur C. Clarke's 1952 novel, *Islands in the Sky*, the main character travels to a space station, where he meets Martian colonists. Forty-six years later, the International Space Station launched. The Martian colonies of Clarke's imagination may happen too—but it probably won't be Mars One, a reality-TV project now regarded as having heart... but no brains.

ILLUSTRATION BY JIM BURNS, ALISONELDRED.COM

<3/</3

Genevieve Valentine, author of *Persona*

None of the celebrities condones it, of course. Supporting truehearting would be terrible publicity. The most anyone says on record is "Be careful out there." (Many stars have clips on GatherApp with 500,000 likes; they're beholden to the crowd.) So they're careful.

For most people, it's enough to show up when the fave needs numbers: There's nothing worse than an audience shot where your area is empty, and the enemy's sections overflow with smugs. But if you do love your fave the most—if you're a trueheart, someone who forswears all others to protect your fave's reputation—your job is sterner stuff. Truehearts patrol the Web, fighting all criticism. They have access to grayspace forums—with daily passwords delivered in encrypted cat pictures—where they map the fave's real-time locations. To hunt the haters is a calling, not a game. (Sometimes you hunt your own. To be a true fan is hard; the world is full of objects to worship. So many fans falter.) The celebrity doesn't know who his truehearts are; they're just strangers shyly begging an autograph.

SOMETIMES YOU HUNT YOUR OWN. TO BE A TRUE FAN IS HARD. SO MANY FANS FALTER.

But no passion's perfect. Firewalls crack; enemies get in. Once an actor found his own forum and made some sharp remarks. He retired suddenly after the backlash—not even his forums can find him now. Only one person knows what happened; a trueheart protects his object at all costs. If the fave can't act in his own best interests, that's just too bad. There's no room for traitors in a trueheart world.

ARTIST NOTE: PATRICK JONES

In a post-apocalyptic world, the cities will become the jungles of future explorers.

Grinding Time

Mary Robinette Kowal, puppeteer and Hugo Award-winning author, whose latest book is *Of Noble Family*

Albina sat crosslegged on the reclaimed-bamboo floor of her condo, with the SmartMortar gripped between her thighs. Leaning into the motion, she ground the pestle with soothing clockwise rotations. She was top of the leaderboard on Grynder, and intended to stay that way. After 50 reps, the mortar chimed: "Good job! Now grind counter-clockwise, and remember to keep your shoulder blades back!"

"Albie?" Light footsteps sounded in the hall, and her husband leaned through the door. Todd sighed. "It's the middle of the night."

"With our flight tomorrow, I won't have time in the morning to grind cornmeal and coffee for breakfast." Albina kept her focus and tried to take deep breaths with each rotation. She was not going to have this argument again. "I'll turn the volume down after I finish this set of reps."

The mortar chirped: "Halfway! Don't forget to breathe."

Todd rolled his eyes. "You could, you know, eat instant grits for breakfast. Just once."

"There's more nutritional value in hand-ground cornmeal." This was true, and she was not going to let Brenda47k move to the top of the leaderboard just because they had an early flight. But Todd would only use that as a reason to complain about her obsession again. "Plus, it's great for my delts."

He sighed again. "You're not... you're not going to bring that with us to Tahiti, right?"

"Of course not, sweetie." She'd checked the gym at their hotel, and they had a full mortar set, including a traditional Tahitian mortar for millet. "It's too bulky."

Exploring Location X

Kim Stanley Robinson's latest book, *Aurora*, comes out in July

They led us into a windowless room, and after that we were left alone for the duration of the trip. We had no clocks or any other tech. There were beds, and a meal was brought in. After that we talked, rested, and eventually slept. It was hard to tell if the dirigible was moving. A couple of days later we felt a slight tilt, and were led down inflatable stairs into the slanting sunlight. We were in mountains somewhere—a high glacial basin surrounded by granite ridges. It seemed we were looking south, the sun shining over a ridge to the west. But then I wondered if it was midmorning, and we were actually looking north. We would find out.

The dirigible disappeared over a ridge, leaving us alone with our backpacks and a week's worth of food. No maps, compasses, or GPS devices. We could only guess where we were. This, after all, was what we had paid for: a mystery on a planet made new to us.

It looked like the Sierra Nevada of California—blue sky and green meadows flanking the ponds and streams. But we had taken off from Salt Lake City, so this could be the Wind River Range.

After a while it became clear that it was afternoon. We would camp now and hike tomorrow. Might take a morning to figure out where we were, might take a week. Unlike in our normal lives, the thrill of unknowing coursed through us.

ILLUSTRATION BY PATRICK JONES

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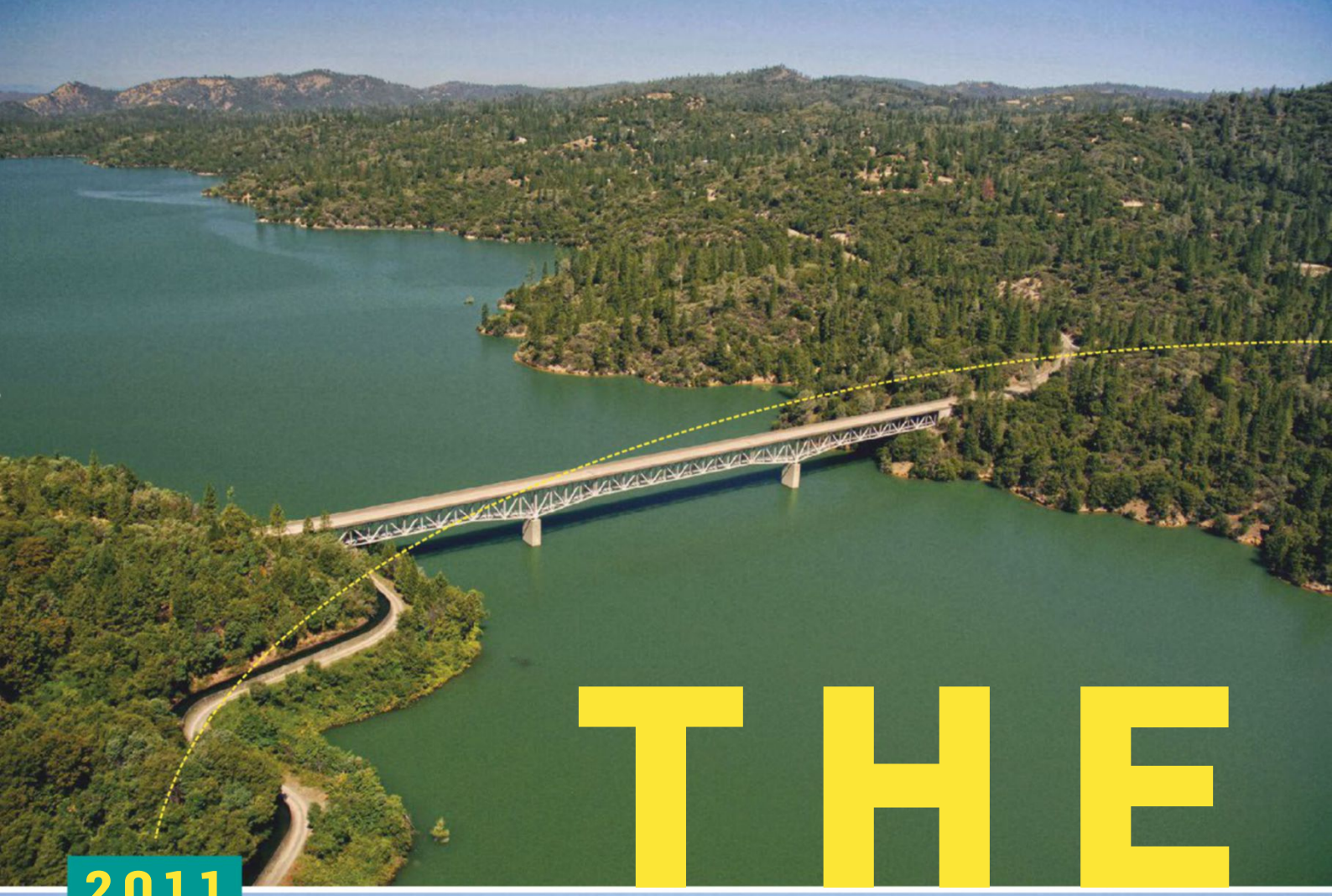


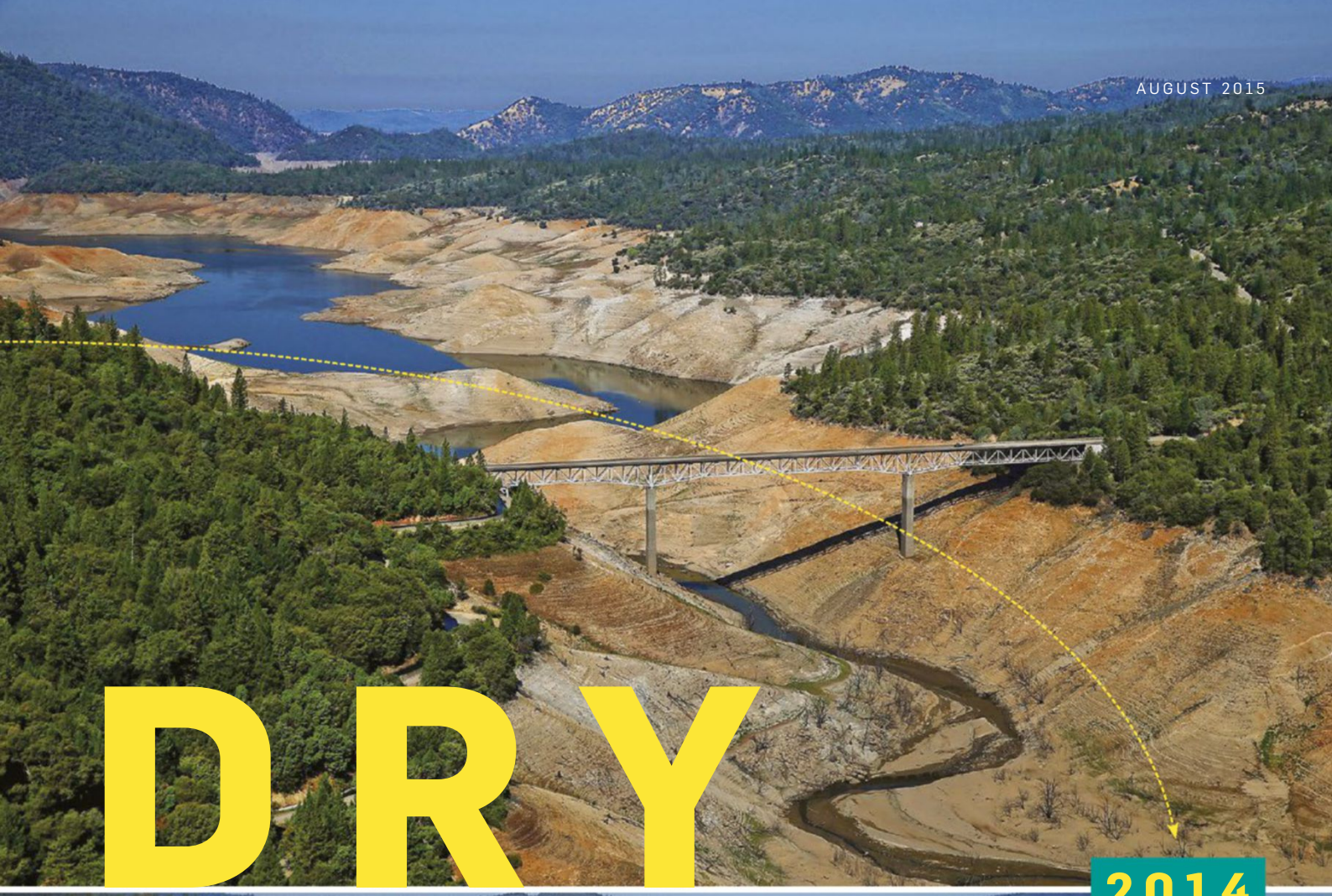
THE

2011

SPE

Lake Oroville, north of Sacramento, is California's second largest reservoir. In late 2014, NASA scientists found that the state would need 41 trillion litres of water to recover from its drought, about 10 times the capacity of Lake Oroville.

JUSTIN SULLIVAN/GETTY IMAGES (4)



DRY ELL

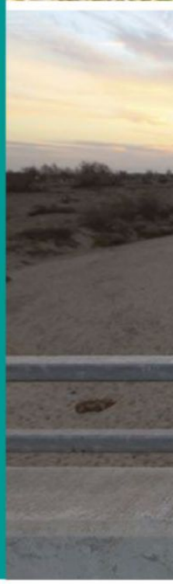
2014

CALIFORNIA IS IN THE FOURTH YEAR OF THE WORST DROUGHT IN ITS HISTORY. WHY CAN'T SCIENTISTS EXPLAIN IT?

BY JENEEN INTERLANDI

ABOUT A DECADE AGO, SCIENTIST LISA SLOAN MADE A DIRE FORECAST: MELTING ARCTIC ICE COULD PRODUCE AN EPIC DROUGHT.

Lisa Sloan is a paleo-climatolgist at the University of California at Santa Cruz.



This winter, Arctic sea ice set another dubious record: the lowest maximum extent. In other words, there was less ice at winter's height than there ever has been.

By changing the path of winter storms over North America, it would send far more rain to Alaska, and much less—about 25 cm, or 30 per cent less, per year—to the American West. The findings were alarming enough to attract national headlines. But before long, all was forgotten, trampled over by a parade of newer studies with their own dire predictions. Sloan's paper could have remained in obscurity—and probably would have—but for one thing: The terrifying scenario she describes appears to be coming true.

In case you've been living in a cave, California is in the midst of what by most measures is the worst drought in the state's history; it began in 2011 and has since claimed the lowest annual precipitation, the highest annual temperature, and the most extreme measurements on record for things like lack of soil moisture and lowest water tables. Governor Jerry Brown enacted the state's first mandatory water restrictions in April. And nearly half of California now falls under the US Drought Monitor's most severe category—"exceptional drought"—where it is expected to remain through at least the rest of 2015. In other words, the worst drought in the state's history is probably going to get even worse.

Meanwhile, on the ground: glimpses of an apocalypse. Homeowners are stealing water from canals, petty thieves are stealing it from fire departments, and god-knows-who is stealing it straight from the San Joaquin Delta. Lawns are brown, farms are fallow—agricultural losses are projected to top US$2 billion—and the Sierra Nevada mountain range is largely snowless. The fake-grass business is booming; the swimming-pool industry is not. Oh, and by the way, the state itself is sinking—because that's how much groundwater has been lost.

Depending on your Facebook feed in the past few months, you might think that this particular drought is definitely being caused

FROM TOP: COURTESY LISA SLOAN; KEEN PRESS/GETTY IMAGES

California Governor Jerry Brown declared a state of emergency in 2014 that remains to this day. Clockwise from top left: the now-brown state capital, reminders of new water restrictions, spray painting a lawn, and a very unappealing swimming hole.

CLOCKWISE FROM TOP LEFT: JUSTIN SULLIVAN/GETTY IMAGES; DAVID N BRAUN (GOWESTFOTO.COM)/GETTY IMAGES; JUSTIN SULLIVAN/GETTY IMAGES; DAVID MCNEW/GETTY IMAGES

by climate change; or that it's definitely not climate change; or that environmentalists are somehow to blame—or perhaps a colossal mass of warm water known as "The Blob" is the culprit. Stacked against Sloan's work, those claims raise a question: How can we forecast something almost perfectly and still not be certain what's causing it?

FIRST THINGS FIRST: No one disputes that the most immediate cause of the current crisis is an entity known as the Ridiculously Resilient Ridge, or Triple R for short. The Triple R is a "blocking ridge," a region of high atmospheric pressure that disrupts normal wind patterns. Imagine a boulder that rolls into a stream and forces the water to flow around it. Blocking ridges are like boulders in the air currents (in this case, the polar jet stream) that carry storms around the globe. They materialise pretty regularly, and can even grow quite large, covering thousands of kilometres in some cases. But they tend to dissipate quickly, usually within a few weeks.

The Triple R has persisted for far longer than that. It was first observed during the second half of the 2012-13 rainy season. By January 2014, it stretched from California to Alaska and was diverting the jet stream, with all its Pacific storms, far to the north—dumping a record amount of rain near the Arctic Circle, and leaving California, Oregon, and Washington parched. The ridge is still there now, where it might remain for some time to come. "It's unprecedented in the observational records," says Daniel Swain, the Stanford PhD student who gave the ridge its cutre name. "And it's the most obvious reason for storms being deflected."

But if the Triple R is causing the drought, what's causing the Triple R?

THE FAKE-GRASS BUSINESS IS BOOMING; THE SWIMMING-POOL INDUSTRY IS NOT. OH, AND THE STATE ITSELF IS SINKING.

This is where things get messy. One potential culprit is melting Arctic sea ice, as Sloan identified in 2004. Normally that ice acts ironically like an blanket, preventing the warmth of the ocean from escaping into the atmosphere. When the blanket disappears, or even just wears thin, heat escapes more readily. In her study, Sloan projected this escaped heat could form Triple R-like columns of warm air that would push Pacific storms northward, in more or less the fashion we are witnessing today.

Melting Arctic sea ice is a consequence of global warming, which is itself a consequence of rising atmospheric greenhouse-gas concentrations. As it happens, Swain and his adviser, Noah Diffenbaugh, found in a 2014 study that a persistent high-pressure anomaly like the Triple R is more likely to occur at current greenhouse-gas levels. Taken together, Sloan's and Diffenbaugh's findings would seem a smoking gun: Climate change is causing the California drought. So why isn't the case closed?

To answer that question, it helps to do a little thought experiment. Imagine a pot of almost-boiling water. Picture a small circle at the centre of its surface. Tiny bubbles

are starting to rise all around that circle. You turn up the heat, and the bubbles come faster and bigger. Eventually one bubble hits the circle itself. Was it because you turned up the heat? Maybe. But bubbles were rising before that point, so one might have hit your circle even if you had never touched the dial. Weather events—droughts, storms, heat waves—are like those bubbles. And climate change is like that finger turning up the heat; you can say that it increased the probability of the bubble rising in that particular spot, but you can't say that the bubble would not have arisen without it.

Hence the immutable truth of climatology: It is impossible to tie individual events to climate change. Further complicating matters is that climate itself is complex, and drought is an ideal example. Yes, heat from global warming can be a contributing factor—heat increases evaporation which, in turn, dries out the land. But a drought's defining feature is lack of rain, not necessarily rising heat. In fact, droughts have been known to occur during cold periods. Added to that, rain and heat are hardly the only factors that need to be considered. Land use (whether a region has more farms or forests or cities or suburbs), ocean currents, El Niño events, or as Sloan's model showed, melting Arctic sea ice, can all conspire to worsen or alleviate any given drought.

The need to avoid absolutes leaves scientists in complicated terrain. For example, many agree that as the planet warms, the American West—the Southwest in particular—will experience higher heat and more evaporative drying. But whether warmer temperatures will actually lead to *less rainfall* remains a source of debate. It doesn't seem to have yet. A recent report from the National Oceanic and Atmospheric Administration states, "The current drought is not part of a long-term change in California precipitation, which exhibits no appreciable trend since 1895." It goes on to say, "[The Triple R is] symptomatic of natural internal atmospheric-ocean variability."

Some use that inherent uncertainty to misconstrue the situation. In April several media outlets used the argument of "natural variability" to blame the drought on environmentalists. The gist was that dry periods in the West are nothing new and yet other areas seem to cope with them well enough. Water just needs to be managed better. By preventing the construction of dams and reservoirs in an effort to save certain endangered fish species, environmental do-gooders have allowed millions of acre-feet (hundreds of millions of litres) of water to be flushed into the Pacific rather than diverted for farming.

Stanislaus National Forest , USA - May 1, 2015: The New Spicer Meadow Reservoir in the Sierra Nevada, in Tuolomne County, is far below normal capacity this time of year. A lack of snow melt has severely affected drinking water, irrigation and recreation throughout Northern California.

There are many things wrong with this hypothesis, but let's stick to the biggest flaw: No matter how well California manages its water supply, it almost certainly won't have enough to meet its growing needs. According to one estimate, those hypothetical dam projects would add just 1 to 2 per cent more water to the state's dwindling reserves. "The argument is total nonsense," says Peter Gleick, a MacArthur Fellow and president of the Pacific Institute. "It misrepresents both the drought's causes and its severity."

IF THE TRIPLE RIS THE SUPERVILLAIN, THE BLOB WOULD BE ITS MINION.

AS A GENERAL RULE humans prefer order over chaos, so climate models are just sophisticated ways of doing what we've always done: trying for a glimpse of the future. But models have their limits. "I liken them to apple-pie recipes," Sloan says. "All apple pies basically consist of the same thing: apples and crust. But the other ingredients might differ, and so might the outcome." Sloan's study relied on just one of those models, and only a few variables, namely sea ice melt. She didn't factor in land use or population or any of a dozen other things that might impact drought. Her findings seem to reflect what's going on today, she says. But they still don't tell the full story.

To truly understand the California drought, scientists have to understand the global climate system, which has countless weird ticks. The jet stream appears to be slowing down and meandering off-course, giving us both the Triple R and its evil trinomial twin, the Terribly Tenacious Trough (which for New Englanders was the culprit behind their winter's polar vortex). Then there's the Blob, a massive layer of exceptionally warm water—90 metres deep and 1,600 km wide—that's settled off the West Coast. Caused by the Triple R, it is exacerbating the drought by warming the air as it heads toward land, reducing the chance for snow or rain even further. If the Triple R is the supervillain behind the drought, the Blob would be its minion.

In February, scientists from Columbia, Cornell, and NASA analysed various climate models to see what the decades ahead might hold. They found that climate change has increased the likelihood that a "mega-drought"—a *decades-long* period of low precipitation and high evaporation—will consume the western United States sometime in the next 30 years. Again, the studies would seem to have found a smoking gun, but the authors cautioned that their predictions are not carved in stone. Even just one El Niño could alter things dramatically.

And therein lies the rub: No one, not even a scientist with access to some of the most powerful computers in the world, can predict the future with anything near 100 per cent certainty. The most they can do is nudge us toward the answers and hope that we make the final connections ourselves, before the water runs out. PS

Manual

EDITED BY *Sophie Bushwick*

STATS

Time 2 hours
Cost $130
Difficulty

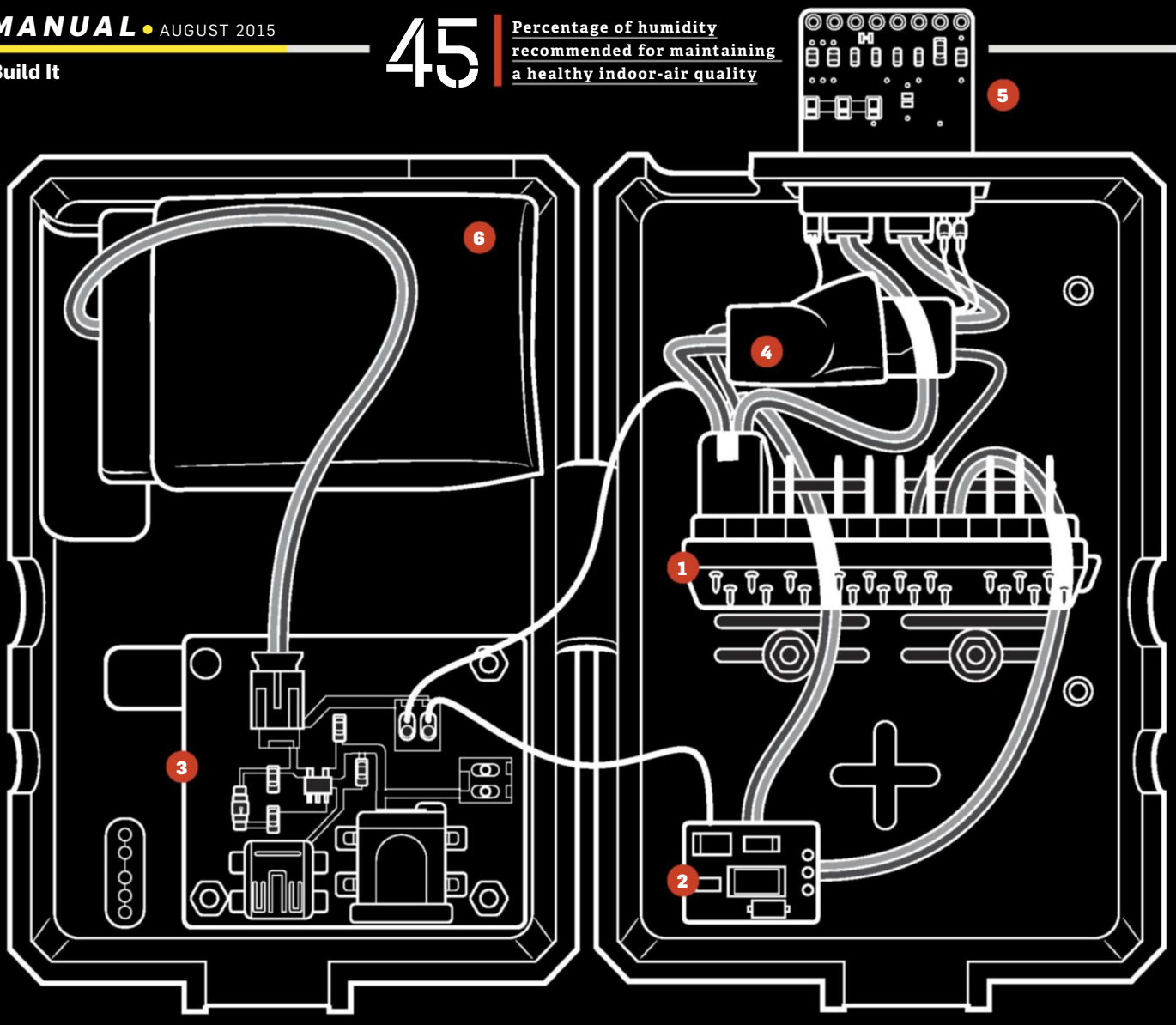
If Your Walls Could Talk...

Wearable technology does a fine job of keeping tabs on your personal fitness. But to measure the health of the place where you live, you need a different tool. This device monitors the temperature, humidity, noise, and light level for any room. It can even track the number of people who enter. Within the casing, a collection of sensors sends information to an Arduino, which interprets the input and displays the data on a small screen. Based on the device's readings, you can turn on a dehumidifier, pump up the aircon, or crack open a window—whatever it takes to keep your home environment comfortable. **DAVE PROCHNOW**

Find this project's code, hookup guide, and more via Google search.

PHOTOGRAPH BY *Jarren Vink*

45 Percentage of humidity recommended for maintaining a healthy indoor-air quality



MATERIALS

- Arduino Pro Mini 328 — 3.3V/8 MHz 1
- PIR motion sensor
- Hookup wire
- Two 1K resistors
- Humidity and temperature sensor
- 5V step-up breakout 2
- LiPo charger basic 3
- Ambient light sensor breakout
- MEMS microphone breakout 4
- Micro OLED breakout 5
- 1,000 mAh polymer lithium-ion battery 6
- Pi Tin for a Raspberry Pi

TOOLS

Soldering iron | Pliers | Wire cutter

INSTRUCTIONS

1 Program the Arduino with the sketch you can find via Google. This is also where you can find a hookup guide. It illustrates the wired connections between each component.

2 Prepare the PIR motion sensor's circuit board by locating and removing the black rectangular three-pad chip (also known as an integrated circuit, or IC) labelled 78L05. On the part of the board where the chip used to sit, identify the now-empty pads 1 and 3. Solder a piece of hookup wire between the pads.

3 Solder a 1K resistor between pin 2 of the humidity and temperature sensor and the 5V pin of the 5V step-up breakout.

4 Solder the humidity and temperature sensor's power pin to the 5V pin of the 5V step-up breakout.

5 Solder the 3.7V pin of the 5V step-up breakout to the output of the LiPo charger.

6 Solder the Arduino Raw pin and the ambient light sensor VCC pin to the LiPo charger.

7 Solder the second 1K resistor between the AL pin of the PIR motion sensor and the 3.3V pin of the Arduino.

8 Solder all power pins of the PIR motion sensor, micro OLED, and MEMS microphone to the 3.3V pin of the Arduino.

9 The key elements of the circuit are complete. Follow the hookup guide to connect the remaining sensor pins to the Arduino.

10 Plug the LiPo battery into the LiPo charger, and put all of the electronics into the Pi Tin.

11 Finally, place the home-health sensor in the room of your choosing. The micro OLED screen will let you keep a finger on your home's pulse.

ILLUSTRATION BY CLINT FORD

TURN UP THE BASS, TURN DOWN THE HEAT

When Seth Robertson and Viet Tran announced that they wanted to build a sonic fire extinguisher, they were met with skepticism. The pair, both engineering majors at George Mason University, could not find a supervisor to support the project. Then they reached out to electrical-engineering professor Brian Mark. "He said, 'I'm the one who's gonna give you the grade, and I won't fail you,'" Tran says. "We were like, 'Great, let's do it!'"

The concept of using sound to suppress fire is not new. Pressure waves push away the oxygen a fire needs and spread the flames over a larger area, reducing heat and weakening the blaze. In 2011, DARPA released a video showing two massive speakers extinguishing a fire placed between them. Robertson and Tran were convinced they could develop this idea into a practical, handheld device.

The trick was finding the right frequency. The students tried for eight months before finally identifying the acoustic sweet spot: low-frequency rumblings in the 30- to 60-hertz range. "When we first put out a cigarette lighter, we were pretty excited," Robertson says. Later they were able to snuff a frying-pan fire in a matter of seconds.

Unlike sprinkler systems or traditional fire extinguishers, the pair's backpack-size Wave Extinguisher leaves behind no chemicals, powder, or water. Eventually, Tran imagines fleets of drones using sound to beat back flames from buildings or forests. This would keep firefighters out of danger and alleviate the need for thousands of litres of water.

87

Firefighter fatalities reported in the U.S. in 2014

After graduating in May 2105, Robertson and Tran formed a company, Force SV, to perfect and commercialise their invention. As Robertson says, "We want to revolutionise how firefighting works." **RACHEL NUWER**

FROM TOP: PHOTOGRAPH BY EVAN CANTWELL; PHOTOGRAPH BY JARREN VINK

Toolbox

The Play-Doh of Glue

Sugru acts like a cross between glue and rubber. When the material is fresh, you can mould it like modelling clay to fix a broken toy, create a custom grip, replace a missing part, or form handy hooks for organising a workshop. But once it sets, a process that takes about 24 hours, it becomes a hardened rubber that adheres firmly to almost any surface. "To make it as useful as possible, I knew it would need to stick to as many materials as possible," says Jane Ni Dhulchaointigh. The Irish inventor developed Sugru over the course of six years, working with scientists on thousands of experiments to perfect the product's shelf life, malleability, and texture. "It was very much a trial-and-error process," she says. Dhulchaointigh's company began selling Sugru online in 2010, and this year it reached the shelves of stores such as Target and Lowe's. Even so, Sugru remains a DIY operation: Its 45 staff members work out of a single building in east London. **SOPHIE BUSHWICK**

Sugru comes in 10 colours, including silver grey. Obviously.

Rise of the MegaBot

In 2013, mechanical engineer Gui Cavalcanti and aerospace engineer Andrew Stroup were competing on a reality TV show where contestants tackled invention challenges. They bonded over a shared lament: the fact that oversize battle robots—a staple of video-games and movies—hadn't yet crossed into the real world. "I told Gui, 'If you find some investor crazy enough to give us money, I promise that wherever I am, I'll come help you build giant robots,'" Stroup says. Cavalcanti found an angel investor the next year, and then software company Autodesk offered its support. Stroup packed his bags and headed to Boston.

Over the course of three months, a "MegaBot" took shape at the Boston makerspace Artisan's Asylum. Stroup was the primary builder, Cavalcanti acted as designer, and Matt Oehrlein, an electrical engineer, handled the electronics and code. The first prototype, made of welded steel covered in sculpted foam, was just a torso on a trailer. An updated model stands 4.5 metre tall and can roll forward on treads at a lumbering 5 km/h. This second prototype holds two humans: A pilot controls directional movement, and a gunner rotates the robot's torso to aim and fire the swappable, arm-mounted weapons. These include a pneumatic cannon that fires 1.3-kg paintballs and a launcher that can shoot 20 smaller paintballs in a row. If one arm falls off, the other can keep fighting.

This January, Stroup left to work for the Presidential Innovation Fellows program, and Cavalcanti and Oehrlein moved the project to San Francisco. They demonstrated their second prototype at the Bay Area Maker Faire, where it demolished a car, in May 2015. By September 2016, they hope the model will be ready to tackle other giant robots.

Large-scale, live robot battles are the ultimate goal. To that end, Cavalcanti and Oehrlein currently are raising a multimillion-dollar investment round. "We're working hard to hook into all the nostalgia built up over a childhood of playing with giant robots in combat games," says Oehrlein. "We want to totally immerse people in that surreal world." **ANDREW ZALESKI**

193

Speed, in km per hour, at which a MegaBot's pneumatic arm cannon shoots 150-mm paintballs

Cavalcanti and Oehrlein with their first MegaBot prototype and a paintball turret

PHOTOGRAPH BY *Alex Gagne*

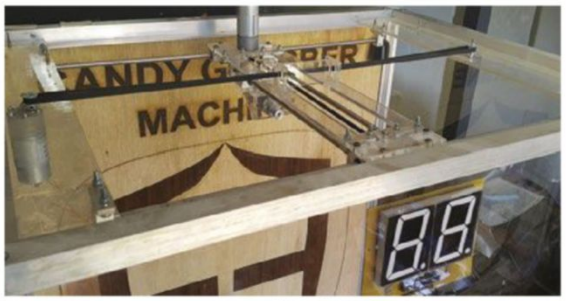
400 | Bags of potato chips Tolba's machine holds

A DIY Arcade Claw

INSERT CANDY

Want to snatch a treat with a candy-grabbing machine? It will probably cost your body weight in coins—unless you follow Mahmoud Tolba's lead and build your own. The engineer at Egyptian startup Integreight wanted to create something fun with 1Sheeld, the Arduino shield his company manufactures. The device attaches to an Arduino to give the board extra functionality, in this case enabling it to interface with a smartphone. Tolba used 1Sheeld to steer a mechanical claw with his phone.

In March he brought the finished machine—loaded with bags of potato chips—to the Cairo Mini Maker Faire. It was, not surprisingly, a hit with kids, who refused to stop playing with it even "when the time ran out and the machine stopped moving," Tolba says. His next project will also dispense food—it's a vending machine controlled by tweets. **RACHEL FOBAR**



How It's Made

Instead of prototyping by trial and error, Tolba designed his candy grabber with engineering software SolidWorks.

With help from a friend, he built the body of the machine from aluminium bars, plywood, and transparent acrylic sheets.

An Arduino controls the claw, made from acrylic pieces held together with screws. Players can input commands to the Arduino through 1Sheeld's smartphone interface.

PHOTOGRAPHS BY MAHMOUD TOLBA

DOG (RE)WALKER

When his cousin's schnauzer, Walt, had a stroke and faced leg amputation in 2002, prosthetics expert Martin Kaufmann put together an improvised brace—even though he had never worked with nonhumans before. Walt kept his leg, and the following year, Kaufmann and his wife founded the world's first veterinary clinic for orthotics (limb supports) and prosthetics in Denver. At OrthoPets, Kaufmann keeps dogs—as well as cats, horses, and even llamas—on their feet. **ANDREW ROSENBLUM**

Why did you switch from treating humans to helping animals?
Walt's stroke led me to ask the question: How come you guys are amputating legs in the animal world when we would use all kinds of other treatments in the human one? The patient's centre of mass varies in a quadruped versus a biped, but most of the physics are the same.

What's your process?
We can't hold down our patients long enough to scan them, so we take a fibreglass impression of a limb, scan that, and make a 3D model. A machine carves the model's final shape from a block of foam, and I vacuum-seal it with plastic. Then that plastic shell goes into final assembly—we add a collection of straps, hinges, pads, and a rugged tread.

06
Average time, in days, to create a veterinary prosthetic

Who was your most unusual and unique patient?
A baby orang-utan. We made orthotics to correct his deformed stance.

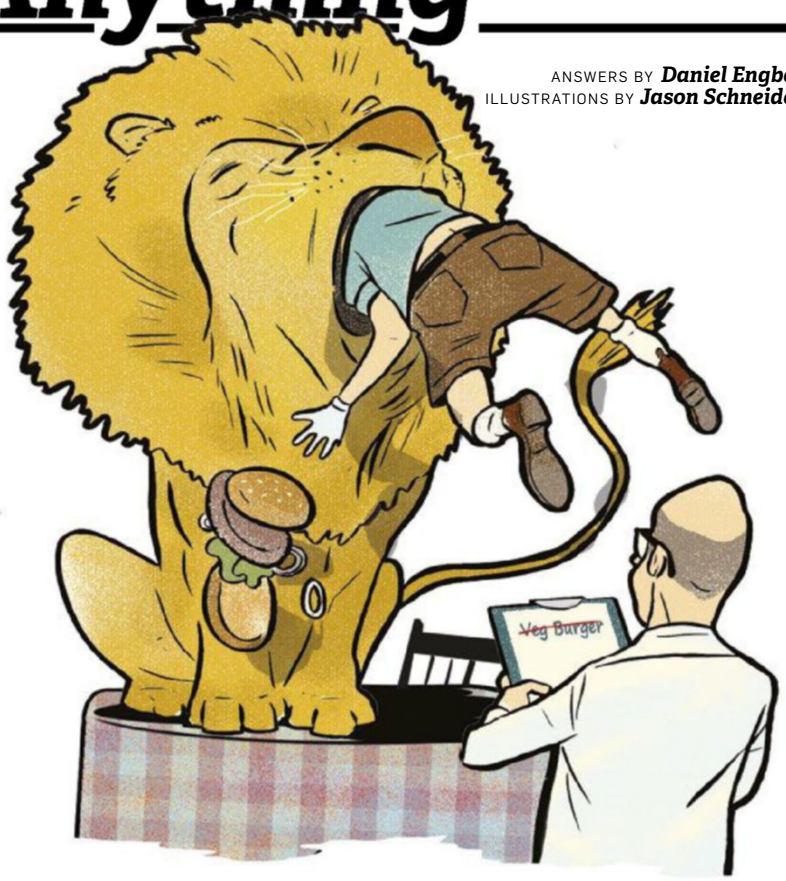
COURTESY OF ORTHOPETS (2)

Go Ahead . . .

Ask Us Anything

Have a burning question? Email it to *letters@popsci.com.au* or tweet it to @popsciau #AskAnything.

ANSWERS BY ***Daniel Engber***
ILLUSTRATIONS BY ***Jason Schneider***



Q: COULD A LION LIVE ON VEGGIE BURGERS?

Short answer Not by a long shot.

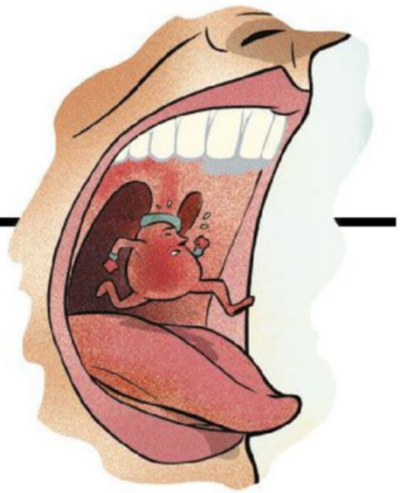
A:

Fake meat, as a rule, garners more complaints than compliments from people. Vegetables lack the complete proteins found in meat, and tend to be a poor substitute for its melange of muscles, tendons, blood, and other tissues—each of which confers a different texture and flavour.

For cats (big and small), it goes beyond mere preference. Felines evolved to be obligate carnivores; in the wild, they must eat meat to survive. Even in a zoo, feeding a lion veggie burgers just won't work, says Barbara Toddes, nutrition program director at the Philadelphia Zoo: "It's like putting petrol in a diesel engine." Lions' teeth are made to slice through flesh, not grind up grains and plant cellulose. Their stomachs mainly use enzymes to break down fats and proteins; they lack the gut microbes necessary to digest carbohydrates.

Domestic cats, on the other hand, can learn to consume veggie kibble if it has a familiar enough texture and consistency, says Kathryn Michel, a veterinary nutritionist at the University of Pennsylvania. But she cautions that it's not exactly healthy or natural. A wholly plant-based diet will leave a cat short of essential nutrients, including taurine and cobalamin. Without them, cats can suffer retinal degeneration, or cardiomyopathy, and possibly urinary-tract problems as well.

Pet owners bent on providing a vegan diet can add synthetic versions of these nutrients to their cat's feed. In a 2004 study, Michel performed blood tests on 17 vegan cats, and 14 of them had normal levels of taurine and cobalamin. So veggie burgers might be palatable for your house cat, but definitely not if that cat is a lion.



Q: How much exercise do we get from talking?

Short answer Not much, unless YOU'RE SHOUTING.

A:

Speaking involves dozens of muscles, and it can be a bit tiring. For a study published in 1998, speech-language pathologist Bridget Russell, of the State University of New York at Fredonia, asked participants to read aloud using either a quiet, normal, or loud voice while she measured their breathing rates, oxygen consumption, and energy use. Russell found that continuous, normal speech is no more exhausting than sitting in silence, but quiet and loud talk both interfere with normal respiration. Most affected were men who read out loud at high volume; they took in 20 per cent more oxygen.

That's on par with measurements in other species. Franz Goller, a physiologist at the University of Utah, has studied the energetic costs of singing in birds. He guessed it would be tiring: A canary erupts in 30-second bursts of song, replete with complicated trills that require rapid "mini breathing," tens of times per second. When he ran experiments on zebra finches, though, which have comparable vocal behaviour, he found their metabolic rates went up by only 5 to 35 per cent while singing. That's about as tiring as cleaning feathers. Or, in human terms, Goller speculates, walking down the street.

Then again, even an easy task grows costly with repetition. "If you spend a penny on something 3,000 times a day, that's still 3,000 pennies," he says. "As a teacher, at the end of a day of speaking, I'm exhausted."

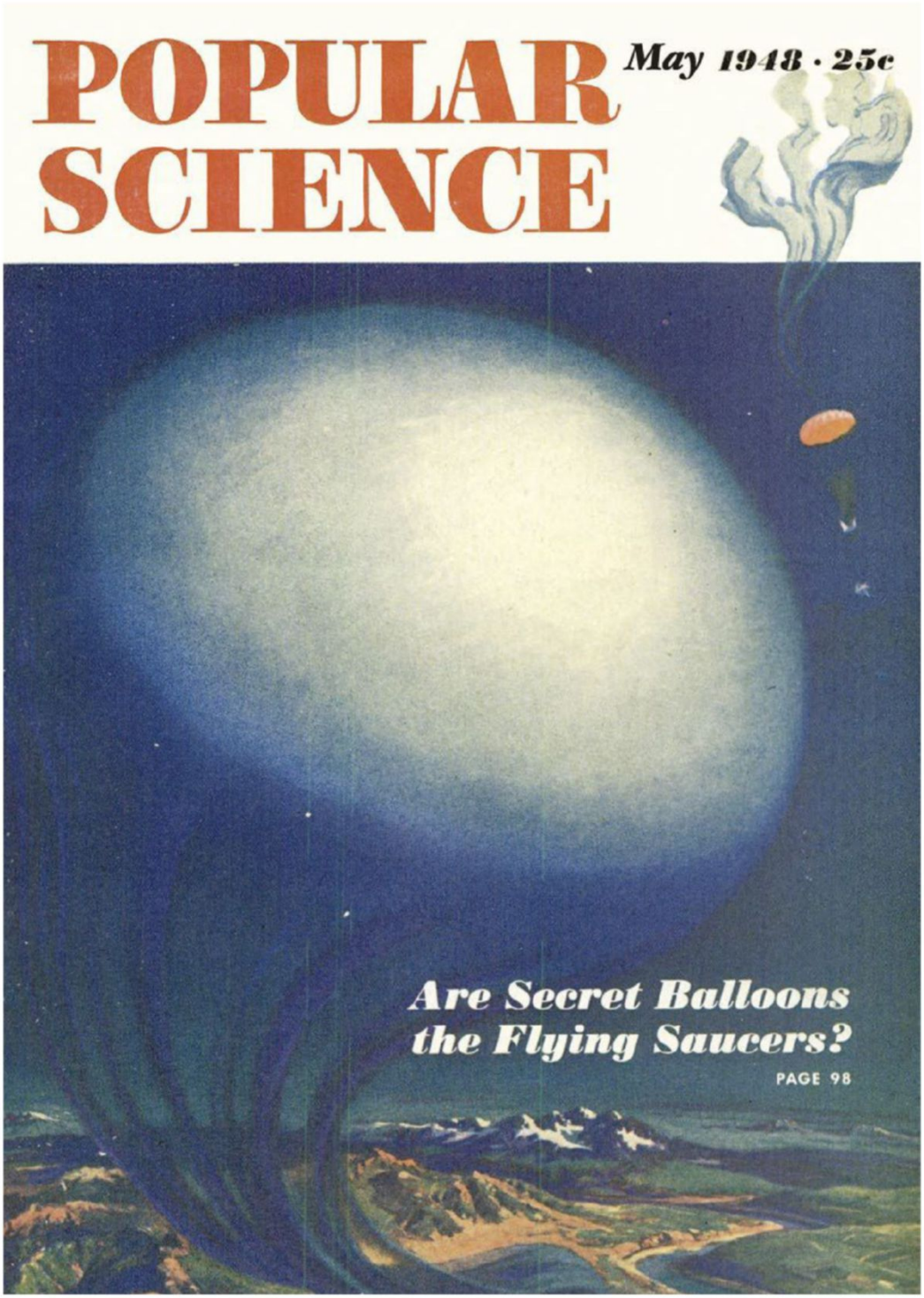
Balloons Explore New Heights

In May 1948, the unmanned research balloon on *Popular Science*'s cover lifted off to explore the stratosphere. As part of Project Skyhook, researchers from General Mills—makers of Halloween-themed "monster cereal"—loaded the balloon with instruments, and deployed it to 30,000 metres to analyse air composition and cosmic rays. "Where our balloons now float will be man's highway of tomorrow," Otto C. Winzen, the project's engineer, told us then. Now, companies are racing to prove Winzen's prediction correct. They plan to lift tourists to 30,000 m using football-field-size balloons that drift on a path over Earth before descending. Read more about how they'll do it on page 36.

RACHEL FOBAR

31

Weight, in kilograms, of weather instruments the Project Skyhook research balloon could support



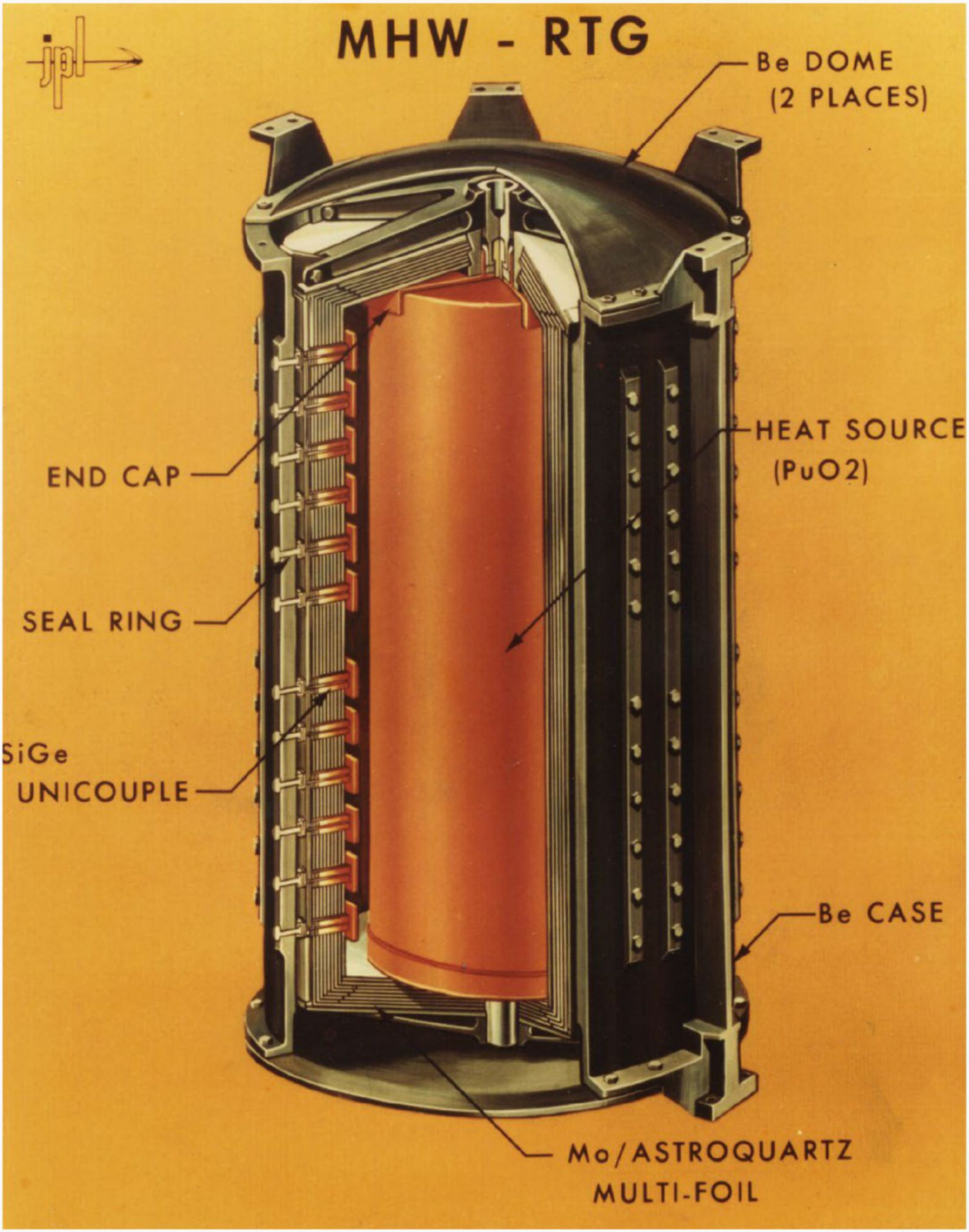
UNUSUAL BALLOON CARGO TAKES FLIGHT

Pet Turtle
In October 1934, Jeannette Piccard became the first woman to reach the stratosphere in a balloon. One of her travel companions was a pet turtle named Fleur de Lys.

Chair
As part of a stunt to advertise a new TV in 2009, DIY space program JP Aerospace helped Toshiba send an armchair more than 29,800 metres up into the stratosphere.

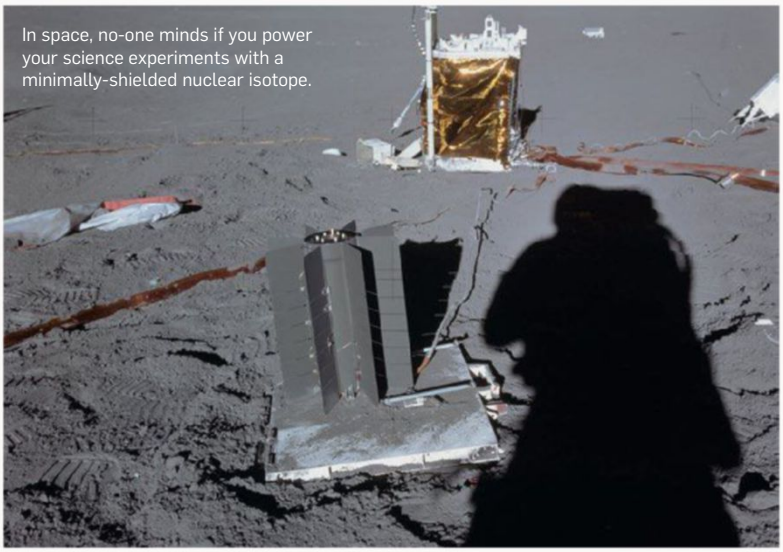
Bobbleheads
During the 2012 election, California middle- and high-school students sent bobbleheads of presidential contenders Barack Obama and Mitt Romney to near-space.

Doughnut
Two Swedish brothers launched the first doughnut (with sprinkles) into the stratosphere above Norway in April 2015. Unfortunately, it returned to Earth in Lake Vättern.


MHW - RTG
jpl
Be DOME
(2 PLACES)
HEAT SOURCE
(PuO2)
END CAP
SEAL RING
SiGe
UNICOUPLE
Be CASE
Mo/ASTROQUARTZ
MULTI-FOIL

RADIOISOTOPE THERMOELECTRIC GENERATOR

Because there's nothing more Cold War than a nuclear-powered lighthouse


In space, no-one minds if you power your science experiments with a minimally-shielded nuclear isotope.

On paper, a radioisotope thermoelectric generator (RTG) is simple. A radioactive nugget releases heat as it decays, which is then turned into electricity via the thermoelectric effect. RTGs can keep working for decades and have no moving parts to break. On the other hand, they don't produce a lot of power for their size, and need shielding to prevent the escape of dangerous radiation.

RTGs are typically installed where other power sources are impractical, and where only a few hundred watts at most is needed. The generators have been used for many different applications, from the military to space travel and even in medicine.

The first RTGs were developed in 1950s by the USA and launched into space in the 1960s. Unlike other nuclear power sources, RTGs only use natural decay, and criticality (and resulting explosion) is impossible.

HOW DOES IT WORK?

RTGs need just the right nuclear fuel - something that puts out plenty of heat but won't decay too fast or release too much radiation.

Typically Plutonium-238 is used, as it produces low levels of gamma and neutron radiation. The heat is turned into electricity through the thermoelectric effect - electricity can be generated from a temperature gradient.

Nestled up to the hot fuel are thermocouples - two conductors that are touching. One side needs to be cooler to create the needed heat flow, so RTGs typically also have an array of heatsinks on the outside.

The system is not very efficient, with only about 3% to 7% of the thermal energy turned into electricity. But that's enough.

As the RTG ages, more of the radioactive material decays, lowering the output.

For example, the isotope of Plutonium most commonly used has a half-life of 87.7 years, which means the energy output drops by about 0.8% a year.

Famous RTG-equipped machines include the Voyager probes. The power systems onboard are now down to just 83.4% of their original output.

WHERE ARE RTGS USED?

One of the main uses for the generators is in space probes. As probes travel to interstellar space, solar becomes significantly less powerful and in some areas it's not possible collect a useful amount of sunlight.

On Mars, the Curiosity rover uses 4.8 kg of Plutonium-238 dioxide to produce 125 watts of electricity, and uses the 2000 watts or so of waste heat to keep warm. The earlier Mars rovers also used radioactive materials to generate heat, but did not convert it to electricity.

Many other space probes such as Cassini and New Horizons use RTGs, as do scientific experiments left on the moon by Apollo astronauts.

Closer to home, RTGs are used to provide power in remote areas such as the Arctic, often for military and monitoring purposes.

The Soviet Union used RTGs extensively to power beacons and lighthouses in inaccessible areas. Even more alarmingly, miniature RTGs were even used in the 1960s to power pacemakers, but have been since replaced with lithium battery technology. Which is less radioactive.

RTGs don't need maintenance, but at the end of their useful lifespan they must be decommissioned carefully to avoid potential radioactive contamination.

ENVIRONMENTAL EFFECTS

Since they contain fairly large amounts of radioactive material, RTGs don't exactly get a Greens seal of approval. The Soviet Union built and deployed thousands of RTGs as power sources in remote areas, many of which are now past their design life span or even lost. Some have been targeted by scrappers who steal the metal shielding to sell, exposing later scavengers to radiation burns. The aborted Apollo 13 mission saw NASA dump a "hot" RTG in the Pacific Ocean. It was designed to withstand re-entry though, and no contamination was released. As far as we know.

RTG 2.0

Despite being less than 10% efficient, there are several projects working on making a better RTG for the future.

Thermophotovoltaics are solar cells that convert infrared (rather than visible light) into electricity. Prototypes have demonstrated a 20% efficiency and the system can be run in tandem with thermocouples.

Thermionic converters use heat to make materials emit electrons and can be up to 20% efficient, but need higher temperatures than current RTGs can provide.

Free-piston Stirling engines coupled to linear actuators and driven by the heat of the radiative decay have run with up to 23% efficiency. These RTGs could be less reliable due to moving parts, but this can be mitigated with non-contact moving parts and sealed operating environments. RTGs might seem like crazy nuke-age kludge tech, but they could have a useful future, especially if our civilisation moves beyond Earth into deep space. **LINDSAY HANDMER**

Labrats

STORY BY ***Subject Zero***

PROJECT TUESDAY

Mars the other One. For very small values of one.

My new agent, former unionist but now free-market evangelist Kurt Blockade, stood at the door of the high school gymnasium and bade me enter.

"But I already said," I said, "I don't WANT to go to Mars."

"Oh come on," he stage-whispered to me, floodlights gleaming on his shaved head. "You don't think this insane scheme is actually going to SEND anyone to actual Mars? It's all a publicity stunt, a great lactating teat that you should suckle on."

I looked at him doubtfully.

"And the milk in this case," he said, "is money." He nodded helpfully and shoved me through the door. This was his style. Not for Kurt Blockade the guaranteed $125 payment. He was more about opportunity.

The opportunity in this case looked somewhat doubtful. The room was full of maybe 200-300 hardcore nerds, many of them in orange jumpsuits. Up the front was a podium. Behind the podium was a man, and behind the man was a Project Tuesday banner. The banner had a picture of Mars in a Viking hat, that had been doing the social media rounds for the last week, since Project Tuesday's CEO, the doubtfully-named Thor Hnafnirson had announced the whole thing on Google+.

"It's called Project Tuesday," said Hnafnirson, as a rather bizarre opening to some kind of speech, "because the word 'Tuesday' comes from the Old English word Tiu, which means Mars." He nodded in a self-satisfied manner.

"Why does it have a Viking hat?" someone yelled from the back of the room. When 300 pairs of angry nerdy eyes swivelled to look at me, I realised I was the one who had asked.

"Because Vikings are awesome!" bellowed Hnafnirson. "We are all descended from Vikings, well not all, but the best of us are! And we are filled with the spirit of exploration, just like the Vikings, who were the first to discover the old New World, you know!"

"I thought those were Icelanders?" I found myself interjecting. Hnafnirson waved a hairy meaty hand dismissively.

"It's all the same, part of a rich tapestry," he said. "Anyway. we're getting off the topic, and the topic today is SPACE EXPLORATION. You've seen hundreds, maybe even THOUSANDS of half-baked, cuckoo-clock plans to colonise the Red Planet, but what have they all had in common?"

"The colony would have collapsed in less than two months!" I bellowed. Damn it, what was WRONG with me? Was I confronting some kind of deep rooted prejudice I didn't even know I had? Do I, fundamentally, hate start-up space explorers and everything they stand for?

"No!" replied Hnafnirson. "Well, yes, but that's not what I'm going for here. The problem with all those kooky space-schemes is they had a bad case of tomorrow-itis! Do you know what tomorrow-itis is?"

The gathered throng made an inchoate noise that came across as meaning, given enough time, they could probably figure out what tomorrow-itis was but to keep the whole thing rolling maybe Hnafnirson should just tell us.

"They always promise to go to Mars TOMORROW!" cried Hnafnirson in triumph. "Or next year, or next DECADE, or whenever someone gets around to building their risk-shy gold-plated space tech. I say HELL NO to that mentality and I say let's go to Mars RIGHT NOW!"

Beaming, Hnafnirson pulled on a rope, and the Project Tuesday banner fell down, revealing a rocket on a launchpad behind him. Now... as a hobbyist rocket at maybe 1:30 scale, this thing was very impressive. It reached all the way to the roof and had sufficient diameter to carry, say, a guinea pig in reasonable comfort. But it was, in all important respects, a toy rocket.

I started to shuffle backwards toward the doors.

"Come on!" cried Hnafnirson. "She's fuelled and ready on the pad!" He made a sort of ushering motion. The nerds in the crowd looked at each other doubtfully.

"Oh right," said Hnafnirson. "I get it. None of you freaks ACTUALLY has the balls to REALLY go to Mars. You all sign up and compete for the limited places and waste my time, on the basis that deep down you think it's never REALLY going to happen. You think you can get lots of social media cachet and heaps of Twitter followers because you're 'on the crew' but when I stand up in front of you and say here is this rocket, fuelled and ready to go, then you chicken out." He folded his arms, petulantly. "Well?" he demanded.

"That's not a real rocket!" said a thin and reedy voice. I grabbed at my throat, but this time, it hadn't been me.

Then a whole bunch of CSIRO unionists burst in and carried Hnafnirson and his rocket off the stage in a storm of expletives and argument about demarcation. It was very sudden but not, I reflected, very unexpected. The 300 space nerds also took this opportunity to leave or, as one of them put it in passing: "Escape with our lives."

As the dust settled and the last of the unionist boots rattled up the school halls, I saw my new agent Kurt Blockade standing there. He looked sheepish.

"Sorry," he said. "Reflex action. Calling the union I mean. I just couldn't stand by and - "

"No worries," I said. "I grabbed someone's wallet when they stampeded. There's like $28 in here."

"Score!" cried Kurt Blockade.

Porsche recommends Mobil 1

First the lightning.
Then the thunder.

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